EAAERE2010

The 1st Congress of East Asian Association of Environmental and Resource Economics

PROCEEDINGS

Hokkaido University Public Policy School, Sapporo, Japan
August 17-19, 2010

WEDNESDAY, AUGUST 18, 2010

Session 01 Organized Session-Environmental Fiscal Mechanism (I)

Session 02 Natural Resource Management

Session 06 Economic Theory of the Environment

Session 07 Economic Valuation (II)

Session 08 Emission Trading (I)

Output based allocation of emissions permits for mitigating the leakage issue for Japanese economy / 586

Presenter(s): Shiro Takeda (Kanto Gakuen University)

Co-author(s): Toshidide Arimura (Sophia University) , Hanae Tamechika (Sophia University/Osaka University), Carolyn Fischer (Resources for the Future) and Alan K. Fox (US International Trade Commission)

Emissions auction and the optimal revenue refund scheme / 623

Presenter(s): Yuanguang Yu (Jinhe Center for Economic Research, Xi'an Jiaotong University)

Impact analysis on emission trading for water pollution control in ise bay basin -Combined use of baseline and credit program- / 633

Presenter(s): Takaaki Okuda (Nagoya University)

Optimal regulations and efficiency losses in international emissions trading under different market structures / 659

Presenter(s): Shi-Miin Liu (National Taipei University)

Co-author(s): Tsung-Chen Lee and Hsiao-Chi Chen (National Taipei University)

THURSDAY, AUGUST 19, 2010

Session 09 Environmental Tax

Establishing a finance and taxation guarantee system for environmental basic public services in China / 691

Presenter(s): Na Li (Chinese Academy for Environmental Planning)

Co-author(s): Li Hongxiang, Ge Chazhong and Wu Shunze

Potential welfare loss from using imperfect environmental taxes / 713

Presenter(s): Inkee Hong (Daegu University)

Dividends of Environmental Tax with Endogenized Time and Medical Expenditures / 764

Presenter(s): Chung-Huang Huang (National Tsing Hua University)

Session 10 Circular Economy (I)

Session 11 Environmental Instruments (I)

Session 12 Water and Cost of Degradation

Using regional economic impact analysis to decide public promotion of seismic retrofit in the Northern Taiwan / 944

Presenter(s): Yenlien Kuo (National Science and Technology Center for Disaster Reduction)

Co-author(s): D. Shaw (President of Chung-Hua Institution for Economic Research), H.C. Lin (National Chiayi University), M.C. Chang (National Taipei University) and T.M. Kao (Ming Chuan University)

Effectiveness of economic compensation for living near a nuclear power station: A comparison before and after a large earthquake shock / 965

Presenter(s): Takaaki Kato (University of Kitakyushu)

Co-author(s): Shogo Takahara and Toshimitsu Homma (Japan Atomic Energy Agency)

Analysis of elasticity of household demand for water in Peking / 975

Presenter(s): Xuzhou Ma (Peking University)

Co-author(s): Shiqiu Zhang, Xuxuan Xie, Peng Yue , Liangchun Deng (Peking University)

Water Quality and Environmental Treatment Facilities: / 988

Presenter(s): Geum Soo Kim (Hoseo University)

Co-author(s): Young Jae Chang (Inje University), David S. Kelleher (Hoseo University)

Session 13 Environmental Fiscal Mechanism (III)

An analysis on statistical indicators and methodology of environmental investment in China / 1003

Presenter(s): Yuantang Lu (Chinese Academy for Environmental Planning)

Co-author(s): Jinnan Wang (Chinese Academy for Environmental Planning)

Government intervened side payment schemes in Japan / 1010

Presenter(s): Hiroshi Yoshida（Tokyo University of Agriculture and Technology）

The optimal environmental tax and urban unemployment in a small open dualistic economy with intersectoral capital mobility: Does environmental protection reduce urban unemployment in the long-run? / 1017

Presenter(s): Ichiroh Daitoh (Tohoku University)

Co-author(s): Masaya Omote (Tohoku University)

Session 14 Circular Economy (II)

E-waste recycling systems in East Asia: A comparative analysis of systems in Japan, South Korea, China and Taiwan / 1038

Presenter(s): Soo-cheol Lee (Meijo University)

Co-author(s): Sung-in Na (Hiroshima Shudo University)

A comparison study of economic instruments for WEEE recycling between two Chinese societies, Taiwan and China / 1054

Presenter(s): Chun-hsu Lin (*Energy and Environmental Research Center*)

Co-author(s): Lihchyi Wen (*Energy and Environmental Research Center*)

An analysis of the effects of the waste tax on the reduction of the final disposal of industrial wastes in Mie prefecture / 1067

Presenter(s): Hidetoshi Yamashita (Hitotsubashi University)

Session 15 Economic Instruments (II)

Gresham's law in environmental protection / 1077

Presenter(s): Jin-Li Hu (National Chiao Tung University)

Co-author(s): Ya-po Yang (National University of Kaohsiung)

Emissions abatement in a production economy: Costminimization versus Investment consumption optimization / 1101

Presenter(s): Lie-Jane Kao (KaiNan University)

Do Environmental Regulations Increase Bilateral Trade Flows? / 1116

Presenter(s): Tetsuya Tsurumi (The University of Tokyo)

Co-author(s): Shunsuke Managi (Tohoku University) and Akira Hibiki (Social Environmental Systems Division)

Session 16 Emission Trading (II)

Economic analysis of linking domestic emission trading schemes / 1160

Presenter(s): Shiro Takeda (Kantogakuen University)

Co-author(s): Makoto Sugino and Toshi. H. Arimura (Sophia University)

Optimal strategic regulations in international emissions trading under imperfect competition / 1181

Presenter(s): Tsung-Chen Lee (National Taipei University)

Co-author(s): Hsiao-Chi Chen and Shi-Miin Liu (National Taipei University.)

Abatement costs by fuel types and cost savings by internal/external trades in Korean electric power industries / 1209

Presenter(s): Myunghun Lee (Inha University)

Session 17 Research and Development

Comparison of technical gap and environmental productivity based on meta-frontier in Korean and Chinese manufacturing Industries / 1228

Presenter(s): Sang-Mok Kang (Pusan National University)

Co-author(s): Moon-Hwee Kim (Pusan National University)

Environmental tax, government's commitment and firms' choice on innovation: Process vs. abatement R&D / 1248

Presenter(s): Shihjye Wu (National Sun Yat-Sen University)

Co-author(s): Tsung-Hsiu Tsai (National University of Kaohsiung)

Endogenous R&D model with energy and division of capital stock / 1265

Presenter(s): Youngho Chang (Nanyang Technological University)

Session 18 Circular Economy (III)

Practices and opportunities of environmental supply chain management in China / 1291

Presenter(s): Xianbing Liu (Kansai Research Centre, Institute for Global Environmental Strategies (IGES))

Co-author(s): Leina WANG (Tongji University) , Jie YANG (Tongji University) , Tomohiro SHISHIME(Kansai Research Centre, Institute for Global Environmental Strategies (IGES)) , Cunkuan BAO (Tongji University), Kazunori OGISU (Kansai Research Centre, Institute for Global Environmental Strategies (IGES))

The study of Taiwan resources recycle fee and subsidy mechanisms of waste plastic container / 1319

Presenter(s): Wei-Lung Huang (China University of Science and Technology)

Recycling cost in Japan / 1337
Presenter(s): Masashi Yamamoto (University of Toyama)
Co-author(s): Thomas Kinnaman (Bucknell University), Takayoshi Shinkuma (Kansai University)

Session 19 Economic Instruments (III)

Green Growth Index and its Policy Feedback / 1368
Presenter(s): Taek-Whan Han (Seo-Kyeong University)
Co-author(s): Geumsoo Kim (Hoeso University) and Dongsoon Lim (Dongeui University)

Optimal strategies for the surveillance and control of forest pathogens / 1380
Presenter(s): Tetsuya Horie (University of Minnesota)
Co-author(s): Frances R. Homans (University of Minnesota) , Robert G. Haight and Robert C. Venette (Northern Research Station USDA Forest Service)

Social benefits of environmental information form geostationary environmental monitoring satellite / 1411
Presenter(s): Young Sook Eom (Chon Buk National University)
Co-author(s): Jong Ho Hong (Seoul National University)

Session 20 Energy- Non-Renewable (I)

Development of Global Century Energy Environment Planning Model and Case Study Analysis / 1429
Presenter(s): Xuanming Su (Ritsumeikan University)
Co-author(s): Hongbo Ren, Weisheng Zhou , Ken'ichi Nakagami (Ritsumeikan University)and Hailin Mu (Dalian University of Technology)

Building dynamic adaptive decision framework of integrated resources under sustainable power development / 1437
Presenter(s): Shao-Pin Hung (National Taipei University)
Co-author(s): Ssu-Li Chang (National Taipei University)

Do agreements enhance energy efficiency improvement and emission reduction? Analyzing current scheme of negotiated agreements on industrial energy efficiency improvement and GHG emission reduction in South Korea / 1468

Presenter(s): Seonghee Kim (The Institute of Energy Economics, Japan (IEEJ))

Session 21 Climate Change Mitigation

Research on carbon dioxide emissions in China / 1484

Presenter(s): Wang Lei (Hokkaido University)

Co-author(s): Fumikazu Yoshida (Hokkaido University)

Global warming action of Taiwan s semiconductor/TFT-LCD industries: How does voluntary agreement work in the IT industry? / 1497

Presenter(s): Shih-Fang Lo (International Division, Chung Hua Institution for Economic Research (CIER))

Cost-benefit analysis for assessing CDM activities for energy technologies in Asian Countries by development of an integrated assessment / 1515

Presenter(s): Koji Tokimatsu (Senior Researcher of the Institute of Applied Energy (IAE) and Visiting Research Scientist of National Institute of Advanced Science and Technology (AIST))

Co-author(s): K. Okajima, A. Murata, N. Nomura, E. Endo

Session 22 Energy- Non-Renewable (II)

Limited diffusion of LPG-powered vehicles in China / 1519

Presenter(s): Vivian Leung (Kyoto University)

diesel. This tipped the balance of Autogas and gasoline, delivering a serious blow to the LPGV development in China.

Motorization and air pollution in Shanghai / 1537

Presenter(s): Fu Zhe (Hitotsubashi University)

Promotion of energy supply from west to east in China / 1549

Presenter(s): Azusa Okagawa (National Institute for Environmental Studies)

Co-author(s): Kanemi Ban (Osaka University)

Paper Participation

How to sustainable use the reservoir with woody debris and turbidity current / 1543

Author: Yih-Chi Tan (National Taiwan University)

Consideration on Framework of Environmental Public Finance Policy in China

WANG Jinnan LU Yuantang ZHU Jianhua GE Chazhong

（Chinese Academy for Environmental Planning, Beijing, 100012）

Abstract: The establishment of environmental finance policy has been an important and urgent task for constructing new road of environmental protection in China. In order to enhance the three major functions of fiscal policies in environmental protection, the paper discussed the establishment of a framework for environmental finance policies, which is supported by the three theories of pricing of public goods, external diseconomy，and supply of public goods, identified three key policy fields of environmental products pricing, green taxation instrument，and public expenditure policy. In addition, the paper designed the environmental finance policy roadmap and put forward specific suggestions on environmental public financing, green taxation and public expenditure.

Key words: environmental protection, public finance, policy framework, budget expenditure

The thirty years of reform and opening up to the outside world has been a thirty years of exploring the way of environmental protection in China. In general, China is still in the middle stage of industrialization with increasing pressure on natural resources and environment caused by the rapid economic growth. In the coming 20 years, the environment and resource pressure driven by China's social and economic development will be further increasing and the environmental and resource constraint will be intensifying due to the continued growth of population and fast economic development, especially as the result of traditional economic growth mode. The materialization of the scientific outlook of development has presented both opportunity and challenge for exploring the new way of environmental protection in China. To adapt to the new situation of environmental protection building up energy-saving and environment-friendly society it is necessary to expedite the development of China's environmental financial policy system, further secure the public fund for environmental protection, and promote the historic transition of environmental protection undertakings.

1 Major functions of public fund in environmental protection

The public fund plays important role in environmental protection which can lead the fund from industries and society to environmental protection while making financial input into the environmental protection undertakings. In general, the public finance is of three major functions:

1.1Resource-adjusting function

Rational pricing is beneficial to adjusting and optimizing the allocation of resource and environmental goods. The market failure is quite common in the field of environment because the environmental goods are of the nature of public goods and externality. Therefore, the public finance must take the important function of supplying environmental protection public goods and allocating environmental resources. By means of pricing, the price leverage on resource saving and environmental protection could be fully exerted, thus adjusting the economic activities that have impact on ecological environment improving the utilization efficiency of environmental resources.

1.2 Behavior-leading function

In the context of existing taxation system, the taxes, fees, and preferential measures on environmental protection have played a positive role in leading behaviors in the whole process of production and consumption. The main taxes and fees related to environmental protection include resource tax, consumption tax, urban maintenance and construction tax, enterprise income tax, pollution charge, etc. In the new round of tax reform, e.g. consumption tax reform, the leading function of taxation for environmental protection has been strengthened.

1.3 Fund- securing function

The financial input by government is an important source of environmental protection investment being able to lead the enterprises' and social funds to be invested in environmental protection, especially the end-of-pipe pollution control. With the continued improvement of fiscal expenditure policy the financial input for environment is increasingly intensified, showing the fund securing role of government public finance in environmental protection.

2 Analysis on existing environmental public financial policy in China

2.1 Pricing of resource-environment goods and resource tax

Resource-environment goods pricing policies include relevant policies on resource-environment goods pricing, resource tax, and fuel oil tax, etc. involving the direct pricing of resource goods and environment goods and indirectly increasing the price of resource-environment goods by means of taxation.

At present, the resource and environmental constraint is increasingly prominent, one major reason of which is that the resource-environmental cost has not been taken into account with the price of resource-environment goods at lower side neither fully reflecting the scarcity of resources nor the costs of environmental treatment and withdraw cost when he resource is depleted*. Early 2007, the National Development and Reform Commission (NDRC) issued《Suggestion on Deepening the Price Reform to Facilitate Resource Saving and Environmental Protection》in which it was suggested that the environmental management cost and the withdraw cost be taken into account in the pricing of oil, natural gas, water, electricity, coal , and land, etc. It was also suggested in the same document that the charging standards of emission fee, waste water treatment fee and solid waste disposal fee be elevated. As one of the links of China's energy policy adjustment, the price reform not only took energy saving into account but also played significant role in promoting the development of renewable energy and adjustment of energy composition. In addition, resource tax and fuel oil tax can play a positive impact on resource allocation.

2.2 Environmental public budgeted expenditure

The accounting item: "211 environmental protection". The environmental protection had been listed as an independent accounting item in the 《Reform Scheme of Governmental Revenue and Expenditure Category》developed by MOF in 2006 and the《2007 Governmental Revenue and Expenditure Category》which were put into implementation since January 1, 2007. The expenditure item of "211 environmental protection" makes environmental protection have an accounting item in governmental budgeted expenditure. This is a basic institution in environmental finance system and also a guarantee of governmental financial input in environmental protection while laying down a foundation for strengthening environmental capacity building, increasing environmental budget at local level. However, survey results show that there is no money under the item of "211 environmental protection" in some local governments.

---

* costs of ecological compensation for the resource depleted areas/cities

The environmental special fund. In recent years, the financial resource out of government budget for environmental protection has been increasing. The central special fund of environmental protection was established in 2004. In 2007, a special fund for emission reduction of key pollutants was established by central finance, which mainly supports the development of monitoring, indicator, and performance assessment systems. MOF issued the《Provisional Regulation on the Administration of the Special Fund for the Water Pollution Control of Three Rivers and Three Lakes" and Songhua River Basin》in December 2007，establishing the special fund for water pollution control of key water basins. In 2007, the《Provisional Regulation on the Administration of the Special Fund as Money Award Instead of Subsidy for the Construction of Pipeline Network of Urban Waste Water Treatment Facilities》was issued in which it is provided that the fund transferred from central government to local government should be strictly earmarked for the construction of pipeline network matched with the urban waste water treatment facilities, thus giving a strong policy guarantee for the construction and operation of waste water treatment facilities. Besides, a special fund for rural environmental protection was established out of central finance in 2008, which encourages and supports the integrated environmental management in rural areas by means of money award instead of subsidy. Though the environmental special funds have provided strong financial support for environmental protection, they tends to be emergency oriented lacking long term comprehensive consideration and effective integration to form synergy.

State bonds for environmental protection. Issuing State bonds by central government has become an important fund raising channel for environmental protection. Since 1998, the construction of environmental infrastructure has been the focus of state bonds investment leading great amount of social capital into environmental protection. From 1998 to 2005, a total of 16.1 billion yuan of state bond had been invested in the construction of urban waste water treatment facilities, which had led 42.9 billion yuan of local fund being invested in waste water treatment. However, since the "11th Five-Year Plan" period, the total size of the state bond for environmental protection has been decreasing. The key environmental protection projects supported by state bonds include industrial pollution control projects in Huaihe river basin and Songhua river basin areas, chrome residue contamination treatment projects, as well as energy saving projects, etc.

Transfer payment. Since the tax reformation in 1994 when taxes had been divided between the central government and local governments, the financial transfer payment has become an important way being employed by the central government to balance the local development and subsidization. In general, the environmental factors have not been fully taken into consideration in making the transfer payment. Since 1998, the central government has increased the budget and the size of transfer payment for ecological conservation and compensation in the areas where economic development is restricted or prohibited, mainly supporting the ecological construction engineering projects, such as the "reforestation of the cultivated land" and natural forest protection projects, etc. In 2005, the central government issued 《Some Suggestion on the Further Improvement of the Ecological Compensation Mechanism》trying to integrate ecological restoration and ecological compensation by government transfer payment. In 2008, a total of 1.48 billion yuan from the central finance had been transferred to the local governments of the water source areas of the "South-to North Water Diversion Project" as an ecological compensation payment.

2.3 Preferential tax policy

So far there is no independent environment tax in China, which is still in the process of discussion. Nevertheless, there are some preferential tax policies with regard to environmental protection. For instance, the preferential treatment has been given to VAT levied on resource comprehensive utilization and waste recycling, in which VAT will be refunded immediately after its collection, or reduced by half, or exempted. In the Law of the People's Republic of China on Enterprise Income Tax taking effect on January 1, 2008, it is provided that the preferential enterprise income tax treatment may be given to enterprises who are engaged in certain kinds of environmental protection, energy saving, and water saving projects, i.e. the income from those projects can be reduced by half or exempted. In addition, the preferential business tax treatment has been provided for by law with regard to environmental protection[2]. The existing measures in implementing the preferential tax policy are far from diverse, only limited to tax reduction, exemption, and refund, not being case-specific, and lacking flexibility, thus affecting the effectiveness of preferential policies.

3. Consideration on Framework of Environmental Public Finance Policy in China

3.1 Overall Goal

Based on the theory of public finance and the requirement of the scientific outlook on development, and in terms of the three functions of public finance in environmental protection to: develop a pricing system of resource-environment products to optimize resource allocation; establish green taxation system to intensify the leading role of environmental protection in economic activities; set up the expenditure system of environmental public finance to strengthen the fund guarantee for environmental protection.

3.2 General thinking

The basic consideration in constructing China's environmental public finance policy framework is to integrate financial and policy resources and develop China's policy system on environmental public finance aiming at coordinating the relationship between environment and economy, intensifying government's guarantee for financial input in environmental protection, realizing green economic growth, resource saving, and optimized resource allocation. In terms of the three theories (pricing theory of public goods, externality theory, and public goods theory), the three functions of public finance in environmental protection will be strengthened thus leading the behavior in the whole process of economic activities including production, circulation, distribution, and consumption, etc., establishing resource-environmental product pricing system, green taxation system , and expenditure system of environmental public finance taking into account of the pollution control at source, process, and the end-of-pipe.

3.3 Framework design

The environmental public finance policy framework will be constructed in terms of the key functions of public finance in environmental protection and the different circulation links of resource, goods and labor[9]. The framework is focusing on three areas, as shown in Figure 1: First, to establish the pricing system of resource-environmental products that could comprehensively reflect the environmental cost and scarcity of resources and indirectly influence resource price by imposing resource tax on resource exploitation, thus realizing resource saving and optimized allocation; Second, greening and reforming taxation system, establishing China's environmental taxation system, which include structure design of China's environmental tax, scheme design of an independent environmental tax, greening the existing taxes, study on the feasibility and way of transforming administrative fees into taxes, rationalizing the establishment of taxes and fees, recommending the reform scheme of environmental tax expenditure. Third, establishing environment fiscal expenditure system and environment public finance system that is conducive to sustainable development, which mainly include clearly defining the administrative responsibility/power and financial power in dealing with environmental issues; earmarked fund for environmental protection in central budget; reformation scheme, implementation programme, and supporting policies with regard to special transfer payment for environmental protection projects and ecological compensation.

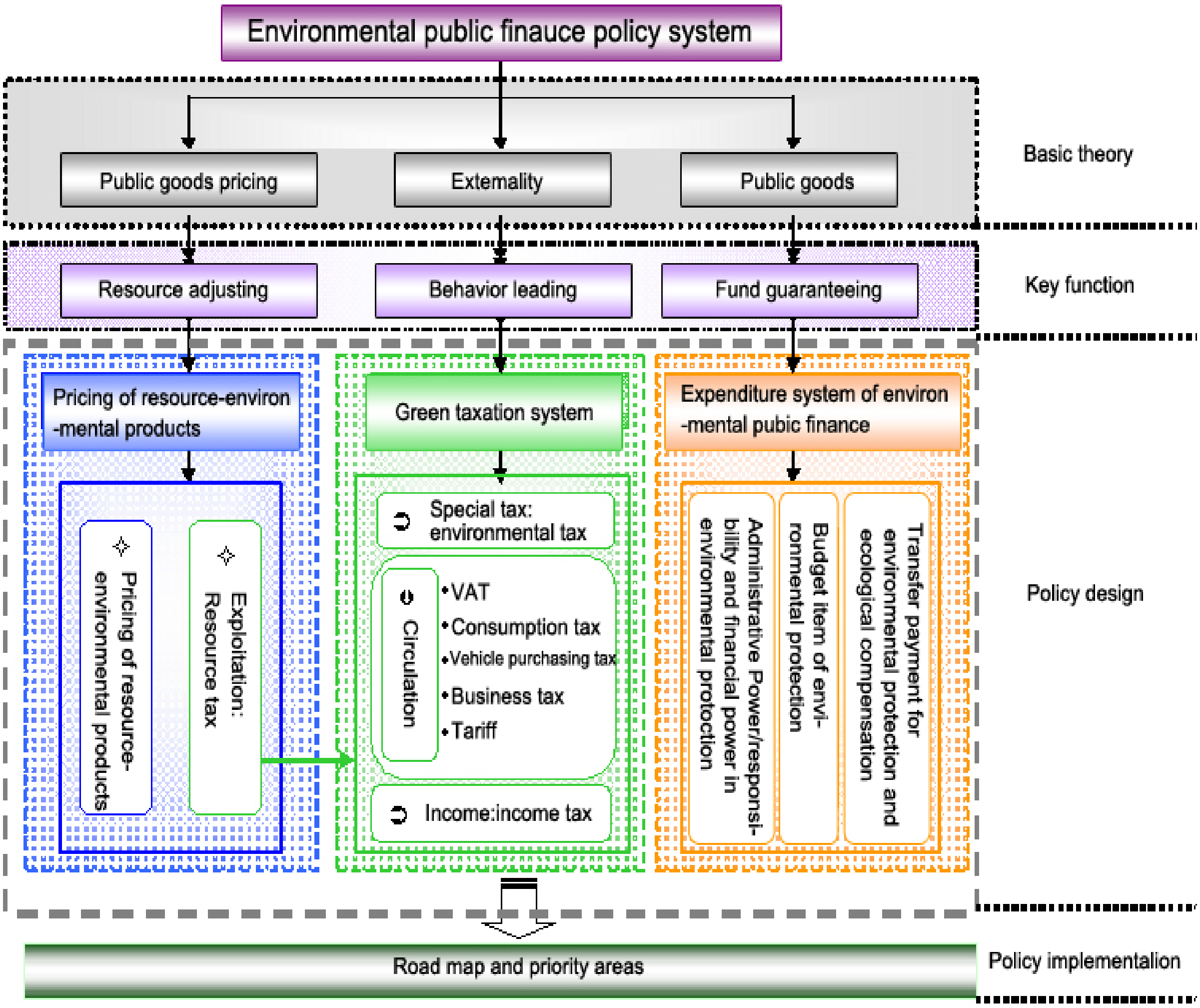


Fig 1. Policy framework of China's environment public finance

3.4 Roadmap of implementation

The establishment of China's environment public finance policy framework should follow the principle of from easier to harder, step by step, and making breakthrough at focused area. The reformation should be arranged on the basis of results and effectiveness of earlier reformation. Under the guidance of the scientific outlook on development and in combination with existing reformation achievements, a road map for constructing China's environment public finance policy framework should be rationally identifies taking into account of the general trend of China's socio-economic development and environmental protection.

Constructing framework and making breakthrough in key areas during the "11th Five-Year Plan" period

In the "11th Five-Year Plan" period, emphases have been put on the construction of the policy framework of environment public finance and making some reform breakthrough in key areas. With regard to the pricing of resource-environmental products, the price reform of resource and environment should be promoted; the preliminary pricing system for resource-environmental products should be established in accordance with integrated planning and implemented in phases. The price supervision over the monopoly sectors should be strengthened. As to greening taxation system, the reform framework for environmental tax will be constructed; an independent tax – “environment tax” will be imposed; the greening process of existing environmental taxes should be accelerated; incorporate environmental requirements into the policy targets of existing consumption tax, resource tax, tariff, and export tax rebate as soon as possible. As for the expenditure of environmental public finance, the administrative responsibility/power and financial power in dealing with environmental issues should be clearly defined; the budget item for environmental protection should be optimized; the budget ration criterion should be set; the scope and ways of using special environmental protection fund should be optimized; pilot implementation of ecological compensation should be conducted; the ecological environment and main functional zones should be taken into account when making transfer payment.

(2) Emphasis on the establishment and improvement of the system during the “12th Five-Year Plan” period

During the “12th Five-Year Plan” period, efforts will be made in followings:

Establishing and improving the pricing system of resource-environmental products, advancing the reformation of resource tax, fully taking advantage of the leverage function of price in resource saving and environmental protection; Broadening and deepening the reformation of environmental taxation system with emphasis on extending the levying scope and optimizing the tax rate. In the meantime, the reform on fees related to environmental protection should be promoted, and the “law of environmental taxes” should be developed in order to elevate the legal status and effect of environmental taxes. Advancing the establishment of carbon tax and setting up the “national fund of energy saving and emission reduction” and “national fund of clean production” by using the carbon tax revenue; Intensifying the development of laws and regulations on environmental public finance system, in which the administrative power/responsibility and the financial power with regard to environmental protection, government’s expenditure on environmental protection, and the central special fund for environmental protection will be clearly defined; Continuingly advancing the pilot work on the construction of ecological shelters in the western area and ecological compensation for the resource depleted cities. Several important policy documents will be issued to intensify the pilot work of horizontal transfer payment for environmental protection between regions and between river basins; Further developing and improving the supporting measures for environmental financial policy to strengthen the implementation of environmental financial policy.

(3) Emphasis on deepening reformation and overall advancement during the “13th Five-Year Plan” period

During the “13th Five-Year Plan” period, efforts will be made in followings:

Further deepening the reform in resource-environmental pricing to comprehensively reflect the resources scarcity, costs of environmental treatment, and the withdraw cost; Strengthening the capacity building in environmental tax administration; Deepening the reformation of environmental public finance system which should be highly in consistency with the national financial framework and supportive to sustainable development.

4 Recommendations on the development of environmental public finance policy in China

4.1 Establishing pricing system for resource-environmental products

(1) Improving the pricing system for resource-environmental products

The multiple factors should be considered in optimizing environmental resources allocation and pricing, including the economic and social bearing capacity and the relationship between pricing by the government and pricing by the market[10]. The reform of resource and environment pricing should be actively promoted, establishing and improving the price formulation mechanism that is supportive to resource saving and environmental protection, fully exerting the fundamental role of market in allocating resources, and leading the participation of the public in resource saving and environmental protection. The pricing policy related to environmental protection and nature conservation should be reformed in order to internalize enterprise's environmental costs. Under the appropriate circumstance the price reform of natural gas could be accelerated, the cost composition of coal should be rationalized, the price reform of electricity should be actively promoted, water price reform should be intensified, the disposal method of domestic solid waste and the ways of collecting disposal fees should be reformed, the price system and market mechanism are need to be improved aiming at promoting the transition of economic development mode. By deepening the price reform, a pricing system will be established that is able to adapt to market change and comprehensively reflect the resources scarcity, costs of environmental treatment, and the withdraw cost.

(2) Accelerating the reform process of resource tax

The main reform tasks of resource finance system are reforming resource tax, rationalizing the distribution of income generated from resources, making all stakeholders be compensated appropriately. Because the resource tax is a local tax therefore the local government, as the principal beneficiary of the tax, shall take the responsibility of addressing the issues such as environmental damage and resource depletion resulted from the exploitation of the resources. It is suggested that resource tax rate for coal, oil, natural gas, and other mineral resources be raised gradually. The basis of resource tax assessment should be changed. That is to change from sale volume based assessment to sale price based assessment of the resource tax, in which the utilization efficiency of resource should be fully taken into consideration. Different or differentiated resource tax rates could be set up taking into account of factors, such as resource property, geographic location, and exploiting conditions, etc. In the long term when conditions are mature, the levying scope of resource tax could be extended to cover water resource, forest resource, and grass land resource, realizing the protection of all natural resources. The utilization efficiency of resource should be taken into account in resource taxation, offering preferential tax rate to the enterprises that have shown high resource utilization efficiency.

4.2 Developing green taxation system

To establish a green taxation system is not only in accordance with national environmental targets and the scientific outlook on development but also raising the fund needed for environmental protection and reduce the loss caused by pollution. Green taxation includes both independent environmental taxes and "greening" the relevant environmental taxes.

(1) Speed up the process of imposing independent environmental tax

The process of developing and imposing an independent environmental tax should be expedited. An independent environmental tax should be added in the existing taxation system that is parallel with resource tax, VAT, etc. Efforts should be made to get policy breakthrough in the "11th Five Year Plan" period. There will be different kinds of environmental tax based on different levying links and tax bases. It is suggested that four tax categories – pollution discharge, polluting products, carbon emission, and ecological conservation – be established.

(2) Promote the greening of taxation

Develop and improve the environmental taxation policy system and elevate the green level of existing taxes. The preferential treatment to consumption tax, VAT, business tax, tariff, and export tax rebate in terms of environmental protection should be further intensified and broadened thus strengthening the incentives of environmental protection to economic activities. If it is difficult to establish the tax category of polluting products, then it can be considered to add new categories in consumption tax covering phosphate detergent, cadmium-mercury oxide cell, ozone depleting substances, over packaging material, disposable (throw-away) dishware that may pollute the environment during or after their use. The consumption tax could be exempted for clean energy (biomass energy). In the long run, coal resource consumption tax may be added putting coal, coke, and thermal power - heavy polluting and highly energy consuming products into the levying scope of consumption tax. The environmental protection products/equipment may enjoy preferential rate of VAT thus promoting their market competitiveness and their use by enterprises; The preferential policy on VAT given to products produced through the comprehensive utilization of waste materials and resources should be further improved. With regard to the business tax, the preferential treatment of tax deduction or exemption will be given to the income earned by environmental technology transfer, consultation, information, and technical services; the preferential treatment on business tax will be given to the income earned from constructing environment-friendly building. Based on the current policy that for the resource-based, heavy polluting, and highly energy-consuming products the export tax rebate will be cancelled or the rebate rate will be decreased. The application scope of the policy should be further extended. The existing restriction policy on tariff and export tax rebate applicable to the resource-based, heavy polluting, and highly energy-consuming products should be further improved, making them bear the corresponding environmental costs. Preferential policies are made to encourage energy and resource saving and emission reduction. In addition to the existing direct preferential treatment of tax reduction/exemption and zero tax rate, various kinds of indirect preferential tax treatment may be employed according to the specific targets and circumstances, such as accelerated depreciation, investment for tax credit, deduction of taxable income, and deduction plus, etc. The policy coordination between preferential treatment of environmental taxes and other taxes should be considered to avoid policy conflict and resulting failure of environmental taxation policy.

4.3 Set up the expenditure system of environmental public finance

(1) Rationally define government’s administrative power/responsibility and financial power in environmental protection

First, clearly define the responsibility of government, market, and the public in environmental protection and pollution control. The core is to put the responsibility of local government and enterprises in place with central government mainly providing policy and financial guidance; second, develop a regime in which the environmental responsibility is matched with financial power, and the administrative power/responsibility and financial power in environmental protection between the central government and local governments are clearly defined. It is recommended that the legal instrument be developed in which the division of administrative power/responsibility and financial power in environmental protection between central government, provincial governments, and municipal/county governments should be well identified.

(2) Budget item of “211 environmental protection”

The fund securing mechanism should be addressed after the establishment of the budget item for environmental protection, intensifying the fiscal guarantee and broadening the fund sources. In reference to the experience in fund administration in other relevant departments (agriculture, science and technology, education, and family planning), the financial input for environmental protection should be increased. If condition allows, the ratio of environmental protection fund in fiscal budget should be determined or the environmental fund should be increased at a rate corresponding to the growth rate of the fiscal revenue. The transfer payment to local government should be increased in order to further guarantee the fund for capacity building of local environmental protection departments and for environmental monitoring, supervision and enforcement.

(3)Intensify environmental transfer payment and ecological compensation

Speed up the establishment of transfer payment system for ecological conservation and environmental protection. In making the governmental general transfer payment and special transfer payment, due consideration should be given to environmental factors and key functional zones. The existing transfer payment projects should be sorted out and reduced. A special transfer payment for key functional zones should be established with transfer payment coefficient to be determined based on the comprehensive ecological effect of the functional zones. The calculation method of transfer payment need to be improved, using “factor method” in stead of “benchmark method”. Establish and gradually standardize the horizontal transfer payment based on environmental factor between regions.

Accelerate the process of developing ecological compensation mechanism and policy system. First, establish river basin ecological compensation fund by means of fiscal transfer payment, water and power surcharge, and etc. The standard of ecological compensation should be developed in accordance with the principle of fare utilization of the river and tailored to local circumstances. A rational assessment indictor system should be developed as the basis of ecological compensation for river basins. Second, the “guarantee money for eco-environmental remediation” and “eco-environmental remediation and treatment fund for abandoned mining areas” should be imposed on mining enterprises, which will be used for dealing with the eco-environmental issues caused by mining and left by the abandoned mines. Third, speed up the development of the ecological compensation standard system for nature reserves. The money of transfer payment for important ecological function zones may come from the government finance or the revenue generated by imposing ecological conservation tax. Fourth, intensify the transfer payment of the central finance for the construction of western ecological shelter by establishing governmental assistance fund, etc, and taking the construction of key function zones as a platform.

References

LU Yuantang, SU Ming, WU Shunze, WANG Jinnan, ZHU Jianhua. Speeding up the Construction of Environmental Protection Fiscal System[J]. Public Finance Research. 2009.3.10-12.

SU Ming, FU Zhihua, Liu Junmin, ZHANG Wei. Review and prospect of Environmental Economic Policies in Cnina [J]. Review of Economic Research. 2007, 27L-1.

ZHOU Shengxian. Implement the Scientific Concept of Development and Explore a New Way of Environmental Protection [J]. Environmental Protection. 2009. 2A. 5-14.

WANG Jinnan, SU Ming, et al. Research on Environmental Financing and Taxation systems Promoting Scientific Development (Internal report).Beijing: Chinese Academy For Environmental Planning.2009.

CHEN Gong. Public Finance[M].Beijing: China Renmin University Press. 2006.

Gao Peiyong. The People’s Well-being & Public Finance[M]. Beijing: China Financial and Economic Publishing House. 2008. 199-227.

Wang Chengyao. A conception on Establishing the System of Environmental Tax [J]. Finance Research. 2009.3.32-36.

The Carbon Tax and Carbon Trading Approach

Daigee Shaw,[1] Chih-Ming Hung, Shih-Fang Lo
Chung-Hua Institution for Economic Research
Taipei, Taiwan

1. Introduction

Climate change is a serious global threat that demands a global response and needs to be treated with the outmost urgency. Governments around the world have begun to place a high priority on the need to reduce greenhouse gas (GHG) emissions. Generally speaking, mitigation options for potential GHG emission reductions have three broad bases: (1) the command and control approach, (2) market-based instruments such as carbon taxation and emission trading programs (also known as cap and trade), and (3) voluntary agreements. Among them, especially with the market-based instruments, there are some apparent similarities between carbon taxation and an emission trading program, which oftentimes adds to the confusion of the world's governments regarding choosing a better mitigation policy instrument that is best suited to their specific circumstances. Furthermore, for governments that consider committing to employing both market-based instruments simultaneously, such as some EU countries, they will have to be very careful not to penalize polluters twice or misuse social resources with a national emission reduction program that incorporates both tools. To address such implementation challenge, this study explores the possibility of a policy mix that combines the two market-based instruments in such an order that the strengths of each instrument can be fully leveraged based on complementarity. Specifically, this study proposes and assesses the carbon tax and carbon trading approach in which carbon taxation is employed in the short term while a carbon trading scheme is set to work consequently in the long term.

In an effort to curb CO2 emissions as well as to promote clean and renewable energy use and the conservation of scarce natural resources, various green tax schemes targeted at the use of depletable energy products have been proposed. Existing green taxes such as an energy tax, an environmental tax, a carbon dioxide tax and a pollution tax are often collectively referred to as the "Ecotax." A carbon tax, in particular, is explicitly designed to reduce carbon dioxide emissions by taxing on the consumption of fossil fuel energy products such as petroleum, coal, electricity and natural gas, based on their carbon content. Also formally referred to as the carbon dioxide tax, a carbon tax is the most important element of a GHG taxation system.

[1] Corresponding author. Email address: dshaw@cier.edu.tw.

Different from the usual mix of air pollutants normally found in the atmosphere that often includes SOx, NOx and some other suspended particulates, the removal of carbon dioxide from the atmosphere depends crucially, not on the use of filtering equipment or other conventional types of cleansing and purification technologies, but rather on the collective action of households and firms in their choice to adopt energy conservation practices or switch to clean and renewable energy sources. A carbon tax, if properly designed and implemented, can be an effective tool to achieve these desirable outcomes, thereby cutting a nation's total carbon dioxide emissions.

The concept of applying a carbon tax to businesses that emit CO2 is: the environmental authority puts a price on carbon emission by arbitrarily setting a tax rate it charges for CO2 emissions. As long as businesses face a marginal cost of reduction that is lower than the tax rate, they will continue to reduce emissions. On the other hand, if the marginal reduction cost is greater than the tax rate, the firms will not commit to any emission reductions. Therefore, the environmental authority can regulate the economy's total stock of CO2 emissions through an adjustment to the carbon tax rate. Currently, most of the Nordic countries and parts of the central Europe are prime examples of countries that have successfully employed various carbon taxation schemes. Specifically, these countries are Finland, Sweden, Norway, Netherlands, Denmark, Slovenia, Italy, Germany, UK, France and Ireland.

Another key strategy to reduce GHG emissions that has been adopted worldwide is the so-called cap and trade systems, whose principles are derived from the Coase Theorem. Under an emissions trading system, the environmental authority sets the needed emission reduction target that is measured in tradable quotas (cap). These emission quotas are then allotted to firms arbitrarily or by using an auction. Due to the differences in firms' marginal cost of reduction, those with low reduction costs could increase their emission reductions and/or trade away their unused emission quotas to firms with high reduction costs. A firm with high reduction costs will agree to such trade as soon as it finds out that the costs of buying these quotas are lower than the costs of reduction it faces. Hence, with a pre-determined target level, an emissions trading system can regulate an economy's total carbon emissions by allowing carbon trades between low- and high-cost firms. That is, through trading a high-cost firm will be able to abate at a lower cost, and a low-cost firm will gain from the sales of its unused emissions quotas. This is the fundamental principle of the Kyoto Protocol's emissions trading design. Since the United States has vast experience in dealing with the pollution of acid rains, the country has been the most vocal advocate of a global carbon trading system, and actively pushes for the system to be incorporated into the Kyoto Protocol. However, as the United States is yet to become a signatory to the Protocol itself, and the EU has begun experimenting with carbon trading since 2005, the EU emissions trading scheme (EU ETS) is currently the world's largest carbon trading system.[2]

Both carbon tax and carbon trading have their own pros and cons. We compare carbon tax and trading from four aspects, which are economic efficiency, environmental effectiveness, administrative complexity, and public finance and social welfare. Carbon tax is superior to carbon trading in terms of economic efficiency, administrative complexity, and public finance and social welfare, but fails to fulfill the environmental effectiveness, we then propose a synthesized approach, the carbon tax and carbon trading approach. With this approach, we can share the strengths of two mitigation instruments.

The remainder of this discussion is organized as follows. Section 2 compares the carbon tax regime with carbon trading. Section 3 proposes the synthesized approach, which called the "carbon tax and carbon trading approach". Section 4 concludes. It is hoped that this discussion will form the initial basis for policy discussions among policymakers and practitioners looking for a viable alternative mitigation option regarding carbon emissions reduction.

2. Comparison of Carbon Tax and Carbon Trading

A. Economic Efficiency

A firm usually has more information about its marginal reduction cost than a regulatory authority. Therefore, in setting performance standards for emission reduction, firms are allowed more flexibility under a carbon tax than under the command and control (CAC). For example, under a carbon tax system, when the reduction cost is high, a firm can choose to pay more taxes in exchange for less carbon emissions reduction; and when the reduction cost is low, the firm can choose more reduction and pay less tax at the same time. In other words, firms decide how much to reduce their emissions and how much tax to pay based on the costs of

---

[2] The global emission trading system can be further classified into one of the subsystems based on the following characteristics:(1) Voluntary and mandatory: the United Kingdom emissions trading scheme (UK ETS), Chicago Climate Exchange (CCX), Japan's voluntary trading system (JVEST) are examples of trading systems based on voluntary agreements; the EU emissions trading scheme (EU ETS) and the reduction system of New South Wales, Australia (NSW GGAS) are mandatory in nature. (2) Area of coverage: cross-boarder and multinational (EU ETS), nation-based (UK ETS, the U.S. CCX, Japan JVETS, Japan CDM), state- and provincial-based (Australia NSW GGAS) and metropolitan-based (Tokyo, Japan). (3) Types of industry subject to regulation: Electricity sector (Australia NSW GGAS), Energy industry (EU ETS, the United Kingdom UK ETS, the U.S. CCX), Transportation industry and residential sector (U.S. CCX, Japan JVETS, the city of Tokyo in Japan etc.).

compliance they face. The certainty about the compliance cost under a carbon tax system allows firms the flexibility to make compliance decisions.

Another attractive advantage of a carbon tax, in terms of economic efficiency, lies in its ability to send a clear price signal on carbon emissions. With such a price, businesses will be able to plan for their production accordingly and make investment decisions relating to emission control equipment and reduction technologies. However, carbon tax is often being criticized for its low updating frequency, as it is usually adjusted on a yearly basis, not amenable during the year to reflect any changes in the actual emission levels in the economy and thereby failing to be effective as a mitigation tool to bring about desired environmental standards. To address this issue, Winkler and Marquard (2009) propose a mechanism in which the carbon tax rate is tracked with the actual levels of emissions reduction that is amendable in every one to two years: that is, if emissions reduction in a given year falls short of the pre-determined level, the tax rate will be adjusted upward; and when reduction exceeds the targeted level, the tax rate will be adjusted downward to close the gap. Hence, through the market forces of supply and demand, the environment authority is able to work with businesses to improve efficiency in their resource allocation decisions.

A well-functioning trading system that is effective and credible in establishing common price signals across countries and sectors will elicit a high level of firm participation that in turn will reduce total reduction costs for all of the participating firms, thereby improving efficiency for the society at large.

Efficiency can be further improved in several ways if the trading system is also structured to 1) provide incentives for a firm to increase reduction so that it can sell its unused quotas to a high-cost firm or country; 2) facilitate an direct transfer of resources across sectors and businesses with different reduction costs, as against an direct transfer of resources to government from the private sector. This is also the main reason why an emissions trading policy is more likely to gain public support than a tax policy-- as it does not involve too much government meddling; 3) Unlike carbon taxes that, if imposed, will adversely add to the inflationary pressures in the economy, and whose real value, if not indexed for inflation, will be eroded over time unless raised periodically, trading system does not have such negative inflationary effects or is subject to the threat of inflation. In fact, the rise in demand for carbon trading, real and nominal, simply translates itself directly to a higher price. And if the trading system is built on a regional or global scale, then all the participating firms will be able to abate at least cost and coordinate production amongst themselves.

Even though both trading and taxes, as a policy tool, can establish clear price signals, trading is more likely to be influenced by the market forces of supply and demand, and easily subject to the changes in market structure and institutions. The fiascoes of EU ETS in dealing with the oversupply of tradable quotas in 2006 should serve as a reminder. In 2006, the trading price for carbon had dropped more than 60% in EU ETS at one point in response to the announcement from the EU government body to outlaw the banking and transfer of the quotas allotted for the first phrase of 2005-2007, to be used in the second phrase of 2008-2010.

Also, from past experience, carbon prices have shown increasing variability and uncertainty under a trading system. Such factors as an economic boom, a price hike in energy costs, a harsh wintry climate or a stringent pre-determined emission target can all result in a huge increase in carbon prices. Similarly, carbon prices may see a huge drop when things go in opposite directions. Nordhaus (2007) provides evidence that carbon prices have fluctuated widely by 200% more than what is seen in the S&P index and the oil prices. To stabilize carbon prices, both IMF (2008) and Pizer (2002) have proposed the use of a “Safe Valve”, whereby ceiling and floor prices are established to limit the variability and firms are allowed to bank or borrow emissions quotas amongst themselves.

B. Environmental Effectiveness

One obvious drawback of a carbon tax system is that the environmental authority cannot be completely sure of the optimal carbon tax rate to set fore each year in order to achieve the desired emission reductions. If the authority inadvertently sets the rate too low, environmental standards will not be met; if too high, then it will weigh down heavily on the overall performance of the economy. Therefore, in terms of setting a limit (or by placing a cap) on total emissions, there is more uncertainty to achieve environmental effectiveness under a tax system than a cap and trade system. Moreover, as the carbon tax is in practice levied exclusively on fossil fuel energy products to reduce the amount of carbon released into the atmosphere, it is not the right tool to regulate other types of GHG pollution emissions.

The most attractive advantage of a carbon trading policy lies in its ability to ensure that the needed reductions in emission are met. As the total emission quantity is pre-determined, an environmental authority can therefore have a clear picture of whether or not the desired environmental standards are being maintained. For example, one of the standards to be met is that, by the Kyoto Protocol the world will reduce the total carbon emissions to 1990 levels by the year 2020. In addition to CO2, the trading scheme can further expand to cover a few other potentially dangerous gases that include methane along with fluorinated gases such as PFCs.

However, the extent to which a trading system can control overall emissions and be effective in achieving the desired environmental standards depends on whether or not the trading policy has a complete coverage of all emission sources. For example, for large trading systems such as the EU ETS, it covers most of the large-scaled European emitters, whose emissions account for half of the EU's total emissions (EC, 2009). Meanwhile, for emitters not yet included in the system, the carbon price they face is zero, as they continue to get away with their emissions without having to pay for the damages they cause. The failure of the system to have a complete coverage of all emission sources gives rise two sets of carbon prices, which adversely distorts the emitter's incentive to undertake more reduction efforts in the long run. In addition, the cost to participate in carbon trading is borne by the firms. Prior to participation, firms are required by law to accurately gauge and report their own emission levels that are first verified and certified by authorized third parties. The compliance procedure is thus made more complicated than necessary for firms to comply. As it turns out, such complex procedure oftentimes is a drain on the firms' resources, and so much so that it could become a formidable barrier for smaller firms with limited resources to be wanting to participate in the first place. As such, it obviously does not help increase the coverage of emission sources with a low firm participation rate.

C. Administrative Complexity

Compared with carbon trading, carbon taxes are easier and cheaper to administer. There are several reasons why a carbon tax system entails a relatively small administrative burden than a trading system. First, carbon taxes can be readily implemented using the existing national taxation systems and administrative structure. Second, as the carbon emissions are indexed to energy consumption, the more energy a firm uses, the more carbon it emits, and subsequently the more it pays in carbon taxes. Also, since the taxes are levied mostly on the upstream emission sources, a process that does not involve monitoring, verifying and registering of the emitting firm's actual emissions record, the costs of administration and compliance are low. Third, the implementation of procedures of a tax system is rather transparent, so it is easier to discourage such behaviors as lobbying or collusion.

Nevertheless, it is going to be a hard sale for the relevant government body to propose to the public the need of instituting a carbon tax. Resistance from both businesses and the general public is to be expected. And the whole process will need more time to seek public support through open discussion and mediation. Furthermore, although it is up to a nation to decide whether or not it is feasible to institute an economy-wide carbon tax to mitigate carbon emissions, addressing climate change by instituting a harmonized global carbon tax is a whole different matter. It is going to be more difficult to coordinate among nations in order to build consensus and move ahead with any practical implementation.

A complex carbon trading scheme often incurs high transaction costs and hurts the economic efficiency. A well organized trading scheme is usually involved many processes to keep the system running well. Those processes include the projections of GHGs emission trajectories, allocation of emission permits, trading of permits, storage or even surveillances of consequent trading, and adding these processes in the trading will necessarily raise the costs of operating the system. In other words, the more complex carbon trading scheme is designed, the higher administration cost it has. In addition, to ensure the fairness in the trading scheme also increase the cost of operating the trading. According to the Coase Theorem, the market will spontaneously reach to an equilibrium once the government allocates the permits or credits to all the stakeholders in the market. However, the amounts of the allocation are directly linked to the costs of each emitter need to spend on reducing the emission. Consequently, each emitter will try to get as more permits as they can through any possible way so as to lower their reduction costs. Therefore, to fairly distribute the permit inevitably requires more resources and also reflect a higher administration cost. For instance, the most common method used by the countries who participates the EU emissions trading scheme is the grandfathering rule to allocate the emission permits. This method relies on each emitter's historical information of emission to distribute the permits. On the one hand, a common problem of this method is that it sometime hampers the introduction of new stakeholders when they have no reference of past emission. On the other hand, those who want to attain more permits may try to emit as much possible as they can.

Another important issue for government to concern is that how attractive a carbon trading would be. The cap and trade scheme is, in fact, more popular than the carbon tax based on some observations, and a well designed trading scheme which attracts more participants can increase the flexibility of the scheme and lower the marginal cost of reduction. The issues such as the fairness or popularity of the ETS will affect the efficiency of the economic instrument and need to be taken into consideration by the governments who may want to use carbon trading as an approach to control the emission problem.

D. Public Finance & Social Welfare

The carbon tax can be a long-term stable source of government revenues; more importantly, the carbon tax can be integrated to be part of an expanded green fiscal reform program – an integrated approach that improves social welfare while reducing environmental damages. In other words, carbon taxes can be revenue-neutral, meaning that government can increase revenues from carbon taxes, energy taxes and pollution taxes and at the same time reduce other distorting taxes, such as income taxes. A portion of the carbon tax revenues could also be used for social welfare payments for low-income persons, subsidies for improving the public transport systems, or reducing government debts. Such fiscal reform program has the potential to yield "quadruple dividend". The first dividend is the promotion of environmental protection and energy conservation. The second dividend is the reduction in tax distortions and elimination of distorting subsidies, which in turn is going to enhance efficiency and improve income distribution. The third dividend is a low tax environment that will help strengthen the country's economic competitiveness, promote low-carbon industries and the development of new energy technologies, and encourage growth-promoting foreign direct investment. Finally, the fourth dividend, arguably the most important of the four, is the establishment of a system of "correct prices" for energy consumption and carbon footprint that is going to have a long-term impact on the development patterns and structures of industries, cities and the modes of transportation. Putting correct prices on carbon and energy use will increase our ability to create a low-carbon and less energy-intensive economy and prepare us for a future of high energy prices.

There are increasing numbers of governments begin to auction the permit recently in order to create consistent revenue from running the carbon trading scheme. For example, EU ETS provide at least 95% and 90% free allocation of permits in the first and second period and begin to auction the permit in the third period. 20% and 70% permits will be auctioned in 2013 and 2020 and the EU ETS will keep increasing the percentage till 100% permits being auctioned in 2027. In fact, many criticize that free allocation of public goods will create windfall profits to private companies and contradict the concept of fair trading. To prevent profits concentrating on certain interest groups, more and more governments have announced to use auction to replace free allocation. In addition, an inappropriate cap and trade scheme will turn out to be a place for rent seeking by interest groups. The problems such as excluding certain industries from the carbon trading scheme, bribing the government officials in order to get more allowances, how to monitor and impose sanctions on those who disobey the rule will eventually become the concerns of implementing the carbon trading scheme.

In sum, compared to carbon trading, the carbon tax has its advantages on economic efficiency, less administrative complexity and more opportunity from the green fiscal reform to creative dividends. However, its deficiency in environmental effectiveness is also recognized. This paper proposes a "", a combination of the two approaches referred to above, with a green tax reform in the short term followed by a carbon trading system in the long term. The methodology and rationale of this synthesized approach are demonstrated in the following section.

3. The Carbon Tax and Carbon Trading Approach

A. Methodology and Rationale

This paper proposes the carbon tax and carbon trading approach that uses carbon taxation in the short term and a carbon trading program in the long term. This framework is based largely upon the analysis of Weitzman (1974), according to whom, short-term efficiency loss is shown to be much smaller under a price instrument such as a carbon tax than a quantitative cap of tradable allowances in the face of risks and uncertainty resulting from asymmetric information in the short run; in the long run, however, the converse is true. This gives rise to a preference of implementing both mitigation instruments in a particular order: combining a tax-like regime in the short run with a quantitative constraint in the long run, so that in such fashion the strengths of each instrument can be fully exploited and leveraged. And as noted earlier, although both instruments meet the first two assessment criteria, they still differ somewhat in cost effectiveness and as a catalyst for the development and application of emission reduction technologies. The differences, as it turns out, require the order of implementation to be specified.

I. Methodology

In the short term or before an international emissions reduction target is specified, a country first ought to adopt a carbon tax. This will not only allow the state to capture tax revenues equal to the size of ABCD as depicted in Figure 1, the government can collect and compile emission data on the recorded emission amount that is equal to the size of CD. In the long run or after an international reduction requirement is specified, it will be in the nation's interest to switch to a carbon trading system. Under the trading system, the nation's previously recorded emission amount (CD) is taken as the initial tradable allowances for the economy, an amount that will be reduced each year. Moreover, in the first year of the trading program, the last carbon tax rate from the taxation system is taken as the price floor for auction or trading. In addition, as suggested by Pizer (1999, 2002), a safety valve with a price ceiling can be used in conjuncture of the proposed price floor in order to limit carbon price to fluctuate within a certain price range, thereby helping reduce uncertainty in firm's compliance costs.

II. The Rationale

The following describes the rationale supporting the carbon tax and carbon trading approach that combines a short-term adoption of a carbon tax and a long-term adoption of carbon trading. Such combination and the specific implementation order find their support in Weitzman theorem, transaction costs and investment incentives. Each is discussed in detail in the following sections.

a. Weitzman Theorem

When comparing the two mitigation policy tools, Weitzman (1974) noted that both price and quantity instruments have their own unique strengths in copying with uncertainty arising from asymmetric information and uncertainty.

In terms of economic efficiency and welfare loss, Weitzman (1974) shows that when the marginal reduction benefit curve (MRB) is flatter than the marginal reduction cost curve (MRC), an unexpected change in the marginal cost schedule will result in a smaller efficiency loss under a carbon price than under cap and trade. And the converse is true when the slope of the MRB is steeper than that of the MRC. That is, the loss in efficiency will be smaller with a quantity instrument than with a price instrument when marginal cost schedule changes unexpectedly. Following Hepburn (2006) and Stern (2007), we illustrate how Weitzman's analysis can be applied as part of the GHG reduction toolkit in the climate-change case in Figure 2.

1) The efficiency of taxes and trading in GHG reduction in the short term

Note that the effect on climate change will only accelerate after the total stock of GHGs in the atmosphere reaches a certain critical level. Before that, variations in emission at any single point in time are unlikely to have a significant effect on the ultimate stock of GHGs. As a consequence, there are few expected marginal benefits of reduction to be had over a short period of time, say a year. This is why the marginal reduction benefit (MRB) curve in the short run is relatively flat or gently decreasing as the quantity of emission increases from left to right.

Similarly in the short run, in order to meet the reduction requirements, emitters including firms and households must make appropriate changes in their production and consumption behaviors, invest in low-carbon equipment and production technology, and/or undergo necessary structural adjustment should the need arises. As a consequence, adjustment costs to meet the reduction requirement can be very high in the near term and such adjustment inflexibility is reflected in a steeper marginal reduction cost (MRC) curve. The intersection of the two curves determines the optimal level of reduction quantity (Q_E) and price (P_E). Note that (P_E) is also the optimal carbon tax rate (T_E) for the same level of reductions under an emission trading system.

Suppose in the short run, with an unexpected change in the marginal cost, the marginal cost curve (MRC'_{REAL}) that lies to the right of the original cost curve (MRC_E)

now becomes the true marginal cost schedule and the optimal level of reductions is now (Q'_{REAL}), as shown in Figure 2A.

Under a trading system with the new cost curve, the total emission reductions will still be fixed at Q_E, a much smaller level than the optimal (Q'_{REAL}); as a consequence, this prevents firms from fully exploiting the advantages of their reduction technologies and the rest of the economy are denied the opportunity to achieve more reductions. This leads to a trading efficiency loss (deadweight loss) that is equal to the size of FGJ (△FGJ). Under a carbon tax system with the new cost curve, the carbon tax rate T_E will induce a greater level of reductions than Q'_{REAL}, a scenario in which firms are induced to achieve more reductions at a higher cost as the rest of the economy try to do the same at a price that is higher than their willingness-to-pay given the carbon tax rate T_E. This results in a tax efficiency loss (deadweight loss) that is equal to the size of HIJ (△HIJ). Figure 2A shows that in the short run when there is uncertainty and asymmetric information, a carbon tax scheme works better than a trading scheme in terms of minimizing efficiency loss (△HIJ<△FGJ).

<u>2) The efficiency of taxes and trading in GHGs reduction in the long term</u>

In the long run or in the scenario where the accumulated carbon stock in the atmosphere has reached the critical level, the marginal benefits of reduction due to any reduction effort will be very high; this is reflected in a steeper marginal reduction benefits (MRB) curve. Moreover, since the marginal cost of reduction faced by the firms is lower in the long run, the marginal reduction cost (MRC) curve is relatively flat. The interception of the two long-run curves gives the optimal long-run reduction level (Q_E) and price (P_E), which also is the optimal tax rate on carbon.

If the actual marginal reduction cost schedule turns out to be MRC'_{REAL} in Figure 2B, the equivalent reduction will be Q'_{REAL}. Under the trading system, since the tradable emission quotas are capped at Q_E, the society as a whole faces a deadweight loss equal to the size of OPQ (△OPQ). Under a carbon tax with the new cost schedule, the pre-determined tax rate is no long optimal; this results in a loss of efficiency equivalent to the size of QRS (△QRS). Figure 2B shows that the tax efficiency loss is greater than the trading efficiency loss (△QRS>△OPQ). Hence, following Weitzman's (1974) analysis, we propose a combination of a tax-like regime in the short term with a quantitative constraint in the long term.

b. **Transaction Costs**

As a vital part to designing an effective carbon trading system, the collection and verification of emission records on emission sources can be very time-consuming and will require a considerable amount of resources; therefore, the transaction costs of carbon trading are high. On the other hand, a carbon tax allows a voluntary self-reporting process to be embedded in the tax system without the need for third-party verification, so that emission data generation requires minimal resources. This translates into low transaction costs for a carbon tax scheme.

Although there is economic incentive for firms to under-report their true emission levels in order to save on carbon tax money, the misalignment in incentive can be corrected if the tax regime is combined with a trading scheme in the long term. This is because the firms will want to be allotted the right amount of emission quotas when a carbon trading scheme is introduced. Also, the emission information collected under the tax system can be used as a basis for allocating emission quotas under the trading system later. Therefore, not only does a carbon tax have the merits of low transaction costs, it can provide the environmental authority with a means to amass accurate emission information. This will help lower the transaction costs of obtaining and verifying the same information for the implementation of the following trading system.

c. **Investment Incentives**

The role of a carbon tax, essentially, is to provide polluters with incentives to continuously search for ways to cut back on emissions by exploring new carbon-reducing technologies. A carbon tax also conveys to investors relatively stable price signals that will enable investor to estimate a rate of returns on their investment, thereby spurring long-term investment for technology needed for addressing climate changes. However, the European experience in carbon trading tells us that high volatility in trading prices has a detrimental effect to the ongoing development of carbon-reducing technologies. Since the mitigation policy is a No-Regret Policy with potentially irrevocable outcomes, it is best to start with a carbon tax scheme whereby potential investors can take advantage of the stable prices to evaluate investment options as they look to develop and diffuse new carbon reducing technologies. This will reduce the costs of reduction in the long run and the economy will be in a better position to achieve desired reduction targets when the carbon trading scheme is phased in.

It is a sad truth that instituting a carbon tax could be very difficult in politics, as it garners few public support for an obvious reason. It creates winners and losers, with impacts on the losers being clearly defined and immanent, while the effects of short-term benefits are unclear and their long-term beneficiaries remain unborn, which makes the proposal easily subject to the lobbying of interest groups formed by the losers who are against such tax schemes.

The carbon trading system usually allots its free emission quotas based on firms' historical emission records; as a consequence, large emitters are more likely to be allotted relatively high emission quotas than small emitters, a windfall only to be had by being a large polluter, so to speak. So, it creates incentives for vested interests to want to support such trading system. Therefore, to make a carbon tax appealing, it should be revenue-neutral. Government can soften the impacts of added costs by reducing other taxes and fees, such as the income taxes, or by paying back the tax revenues in the forms of social welfare payments for low-income persons and subsidies for improving the infrastructure of the public transport systems. It will create jobs and investment opportunities in the process. It will also soften the impacts on low-income earners and weaken the political stranglehold of vested interest groups who prefer carbon trading to a carbon tax.

Instead of relying on historical emission records to determine the allotted quotas, the carbon trading system following a carbon tax in the "" can be improved to use an auction process for the allocation of emission quotas since the emitters are used to pay for carbon emissions under the earlier carbon tax system. Not only will competitive bidding correct the windfall problem, it can help diffuse the opposition to a carbon tax, thereby increasing economic efficiency. Furthermore, revenues generated through competitive bidding could be re-distributed in much the same way as the revenue-neutral carbon tax, so as to create multiple dividends.

4. Conclusion

Carbon tax has been adopted by several European countries, in the hope of creating a low-carbon society and ensuring sustainable growth. Various carbon trading programs, on the other hand, have been adopted by the Kyoto Protocol and currently being developed and tested in EU as a partial remedy to the greenhouse gas (GHG) problem. Both approaches serve to put a price on carbon emissions. Both have their own advantages and drawbacks.

This paper proposes a carbon tax and carbon trading approach, a combination of the two approaches referred to above, with a carbon tax in the short term followed by a carbon trading system in the long term. Our synthesized framework is derived from the Weitzman Theorem, and the concepts of externalities and quadruple dividend. We describe how an environmental authority, using the proposed approach, can achieve the following goals simultaneously: environment protection, economic efficiency, and fiscal sustainability.

References

Duval, R. (2008). A taxonomy of instrument to reduce greenhouse gas emission and their interactions. OECD Economics Department Working Paper, 636. Paris: OECD.

European Commission (2009). *The EU Emissions Trading Scheme*. Brussels: EC.

Government Accountability Office (2008). Expert opinion on the economics of policy options to address climate change. *United States GAO Report to Congressional Requesters*. Washington, DC: U.S. Government Printing Office

Hepburn, C. (2006). Regulating by price, quantities or both: An update and an overview. *Oxford Review of Economic Policy, 22*(2), 226-247.

International Monetary Fund (2008). *World Economic Outlook 2008*. Washington D.C.: IMF.

Nordhaus, W. (2007). To tax or not to tax: Alternative approaches to slowing global warming. *Review of Environmental Economics and Policy, 1*(1), 26-44.

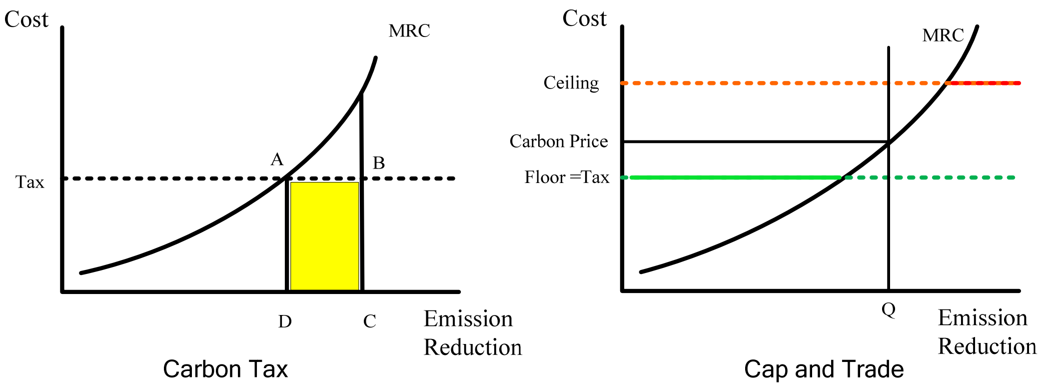
Pizer, W. (1999). Choosing price or quantity controls for greenhouse gases. *Climate Issues Brief, 17*. Washington, DC: Resources for the Future.

Pizer, W. (2002). Combining price and quantity controls to mitigate global climate change. *Journal of Public Economics, 85*(3), 409-434.

Stern, N. (2006). *The Economics of Climate Change: The Stern Review.* Cambridge and New York: Cambridge University Press

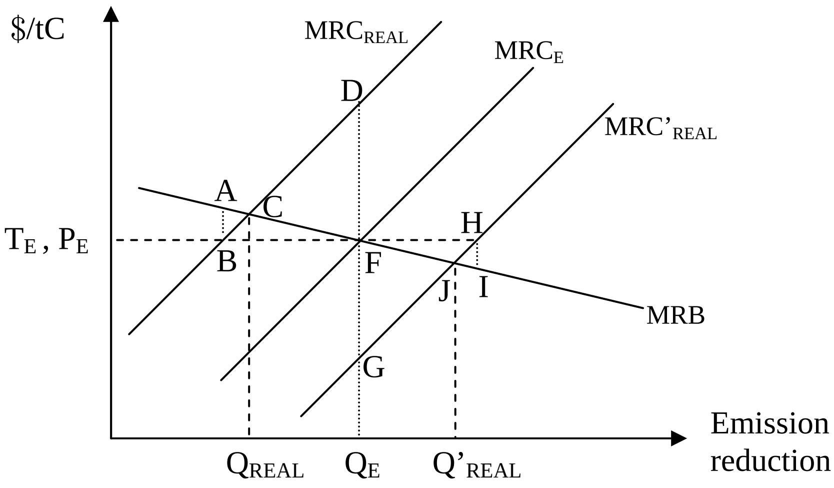
Weitzman, M. (1974). Price vs. Quantities. *The Review of Economic Studies, 41*(4), 477-491.

Winkler, H., & Marquard, A. (2009). Analysis of the economic implications of a carbon tax. The Economics of Climate Change Mitigation Project. Cape Town: University of Cape Town Energy Research Centre.

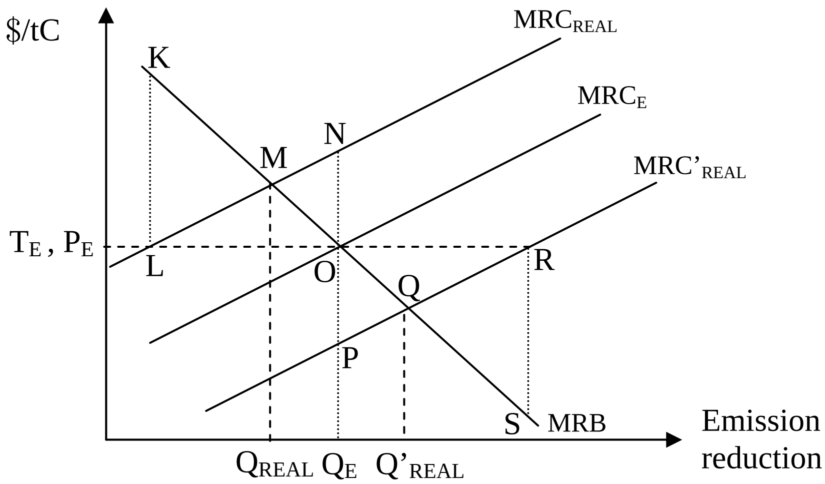


MRC: Marginal reduction cost

Figure 1 A Transition to Cap and Trade from a Carbon Tax



（A）Efficiency loss in the short term under carbon taxation and trading



（B）Efficiency loss in the long term under carbon taxation and trading

T_E: Carbon tax rate; P_E: Carbon price; Q_E: Tradable quotas;

MRC: Marginal reduction cost; MRB: Marginal reduction benefits

Figure 2 An application of Weitzman's analysis in GHGs emission reduction

AN OVERVIEW OF FISCAL REFORM TOWARD SUSTAINABLE DEVELOPMENT IN VIETNAM

Le Thi Kim Oanh,
Danang University of Technology, Vietnam

1. BACKGROUND AND RESEARCH OBJECTIVES

1.1. Background

Vietnam is a developing country in South East Asia that has been enjoying extensive economic growth during several past decades. High speed development of the Vietnamese economy has also resulted in increasing environment degradation. This is among the greatest challenges to the sustainable development of the country in the near future. Therefore, the Government of Vietnam has strongly committed that environmental protection is always an important duty. For attaining environmental protection objectives, the government has utilized various tools in environmental management ranging from command – and – control means to economic instrument such as taxes and charges. Recently, the government also put its significant concerns to environmental fiscal reform toward sustainable development.

This paper is an overview of the recent development in environmental financing in Viet Nam. At a very broad aspect, the paper aims to provide a factual basis for reviewing the interactions between the development of environmental policies and economic development plans in Vietnam in order to enhance environmental management tools to ensure sustainable development of the country. Specifically, this paper is to provide a review on the progress of environmental fiscal reform which has been taking place in very recent years emphasizing on the intensive use of market based instruments, especially environmental related taxes and charges, to control environmental harmful activities and to create revenues for the governmental budget to be able to invest into environmental improvement and fostering sustainable development as well.

1.2. Methodology

This paper is developed based on the qualitative analysis method. Sources of data for analyses are obtained from directly interviews conducted with the officials at the Ministries and governmental institutions which are most related to the process of formulating national environmental policies and strategies and national economic development plans such as Ministry of Natural Resources and Environment, Ministry of Finance, Ministry of Planning and Investment, Vietnam Environmental Protection Agency, etc.

1.2. Focused Research Issues

This research paper will focus on the following issues:

(1) Legal basis for environmental policies and environmental fiscal reform in Vietnam: this part provides an understanding on the evolvement of environmental legal system in Vietnam since 1990s. A description on the formulation and main objectives of National Action Plan/Strategies on Environmental Protection is also provided to give clearly understanding on the legal basis for applying market based instruments as well as for environmental fiscal reform being able to take place in Vietnam.

(2) Current status of government environmental budget at the central level: This part is a review of the progress in central government budget annually as an evident of the keenness and efforts of the Government of Vietnam for integration of environmental concerns into socio-economic development plans of the country toward sustainable development.

(3) Description and comments on existing taxes and charges which are directly related to environmental protection purposes: As an illusion of realization of market based instruments applied in environmental management of the central government in Vietnam, this part is a statistical description of taxes and charges directly related to environmental protection objectives which have been applying so far. In addition, the comments on the impacts of these taxes and charges on environmental pollution mitigation are also provided.

(4) Evaluations on the future prospect of environmental fiscal reform and suggestions for establishing green budgeting in Vietnam. Those recommendations are as anticipated findings for this research up to present.

1.3. Expected Results

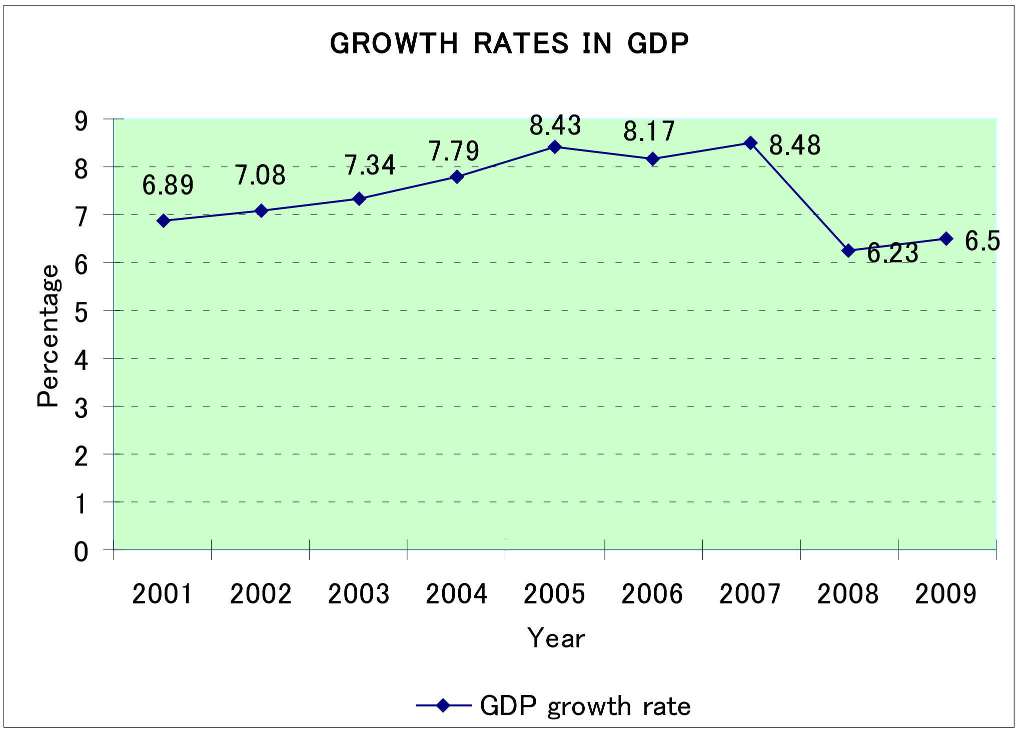
As a result, this paper provides an overall picture on the progress toward greening governmental budget as a useful initiative on environmental policy integration process in Vietnam.

By a thorough review of current situation on environmental budget and fiscal instruments in Vietnam, the research will point out several main challenges to greening budget in revenue and expenditure sides in Vietnam. To help overcome these existing challenges, the research also proposes a number of suggestions on how to effectively and efficiently implementing environmental tax reform to ensure sustainable economic development of the country.

Recommendations will be made with focusing on measures to improve the effectiveness of existing environmental fees and charges. Besides, the research also suggests on how to push the Law on Environment Taxes which is on draft to become feasibility.

2. ECONOMIC DEVELOPMENT AND PRESSURE ON INVESTMENT FOR ENVIRONMENTAL PROTECTION

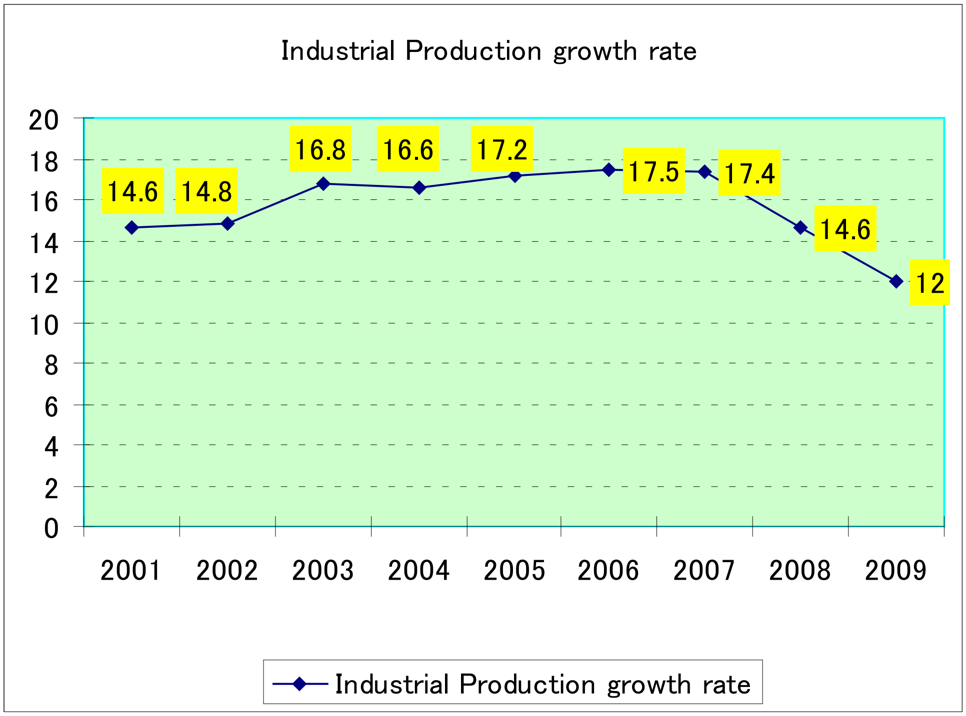
Similar to other developing countries in South East Asian region, environment in Vietnam have been being under a great pressure resulting from economic growth at fairly high rates during the first decade of 21 century. Average economic growth rate is around 7.5% per year during this period as shown in the graph 2.1 below.



Graph 2.1: GDP growth rate during the period 2001 – 2009

(Data source: Based on the annually data in Statistical Yearbooks released by General Statistics Office of Viet Nam)

An important contribution to such remarkable economic growth rate is the continuously development of the industrial sector which causes high pressure on environment at all the time. The share of industrial growth rate in the country's GDP increased from 37.7% in 2000 to 42.6% in 2007. Most of priority industries (e.g., metallurgy, electronics, cement, sea-food processing, etc.) are high resource consumption and generate high level of pollution.



Graph 2.2. Growth rate of industrial sector from 2001 - 2009.

(Data source: Based on the annually data in Statistical Yearbooks released by General Statistics Office of Viet Nam)

Table 2.1: Major Economic Indicators in the period 2001 – 2010

Year	GDP in VND (billion VND)	GDP growth rate (%)	GDP per capita (USD)	Industrial Production Growth Rate
2001	481,295	6.89		14.6
2002	535,762	7.08	440	14.8
2003	613,443	7.34	492	16.8
2004	715,307	7.79	553	16.6
2005	839,211	8.43	639	17.2
2006	973,791	8.17	723	17.5
2007	1,144,014	8.48	834	17.4
2008	1,478,695	6.23	1034	14.6
2009	1,813,000	6.5		12
2010	1,931,300	6.5		

(Data source: Based on the annually data in Statistical Yearbooks released by General Statistics Office of Viet Nam)

Besides, the development of agriculture and fishery are not sufficiently sustainable due to improper use of chemicals and pesticides in agricultural practice are prevalence, and overexploitation of the aquatic product leading to a huge decline in catch yield.

Unbalance urbanization and insufficient urban technical and sanitary infrastructure are also the causes of intensive pollution, especially water pollution. Taking Hanoi city as an example, there are 6 over 15 industrial zones and 36/105 hospitals are equipped with waste treatment facilities[1].

According to the MONRE reports, over the country, 90% of old industrial facilities have no adequate wastewater treatment systems, so that almost all urban wastewater is discharged directly to environment without prior treatment. The latest SOE report (2008) showed that the volume of waste water (incl. industrial, urban domestic, and hospital waste water) discharge directly into surface water

[1] The 2005 State of Environment Report, Vietnam Environmental Protection Agency, MONRE.

source is 3,110,000 m^3 per day, and only 4.26% of total wastewater is treated to meet with Vietnamese standard.

Besides, 70% of industrial wastewater from industrial zones is discharged directly to environment. Almost all urban wastewater is discharged to environment without prior treatment. There are few waste dumping sites which have wastewater treatment system in operating.

Hoa Khanh IZ wastewater
(Da Nang)

3. LEGAL BASIS FOR ENVIRONMENTAL POLICIES AND ENVIRONMENTAL FISCAL REFORM IN VIETNAM

In the past periods, initially important results have been made in environmental protection work. This can be attribute to due attention increasingly paid by the country in the implementation of the Law on Environmental Protection and the Politburo of Vietnam Communist Party Directive 36/CT-TW on Strengthening of Environmental Protection in the period of National Industrialization and Modernization of the country.

3.1. Legislative Foundation:

3.1.1. Environmental protection legislation

The first "Law on Environmental Protection" of Vietnam was passed by the Vietnam National Assembly on 27/12/1993 and came into force from 10/ 01/ 1994.

Besides this Law, the Government has also promulgated many laws and regulations which directly related to environment protection activities, as follows: Forest Protection and Development Law (1991); the People Health Protection Law (1989); Land Use Law (1993); Law of Oil and Petrol; Mineral Resources Law (1996), Water Resources Law (1998); Criminal Affair Law (reform, 1999); Dykes Protection Ordinance (1989); Ordinance of Resources Taxes (1989); Ordinance of Aquatic Resource Protection (1989), Ordinance of Radiation Safety and Control (1996), Ordinance of Vegetation Protection and Quarantine (1993). In order to elaborately instruct the implementation of the above laws and ordinances, hundreds of legal documents have been issued by the Government, the MONRE and other line ministries.

After ten-year implementation of the first Environmental Protection Law, although positive effects have been registered, the shortcomings do exist in the legislation, especially in its enforcement. The system of policy and legislation on environmental protection has been constantly reviewed, revised, and supplemented to address the developing situation. The revised Law on Environmental Protection was passed by the National Assembly in December 2005 and takes effect from July 1, 2006. This revision marked the significant vision change in the management of the environmental protection in the country in terms of both quality and quantity.

Along with the promulgation of the basic Laws, the system of environmental standards have been amended, complemented and issued (first issued in 1995, amended in 2001 and 2005)

3.1.2. Formulating and implementing environmental protection policies

The environmental policies for sustainable development of Vietnam were first systematically presented in the "National Plan on Environment and Sustainable Development, 1991-2000" that was approved by the Government in 1991. Since then, government has promulgated a series of policies for environmental protection and sustainable development, such as the policy on prohibition of fire-crackers production, transport and use; policy on land and forest entrustment for people; policy on reforestation in denuded land and bare hills; policy on promoting use of cleaner technologies; policy on biodiversity protection, policy on closing natural forests; policy on potable water supply and environmental sanitation in rural areas, and the programs for decreasing population growth rate etc.

In May 1998, the Politburo of Vietnam Communist Party issued the Directive 36/CT-TW on Strengthening of Environmental Protection in the period of National Industrialization and Modernization of the country. This is the first time the leading Party of Vietnam has promulgated a document to address environmental concern and direct the implementation of environmental protection activities of the country.

Under the guidance of this important directive of the Party, in 2003 , the Ministry of Science, Technology and Environment have formulated the "National Strategy for Environmental Protection to 2010 and vision toward 2020" and submitted it for approval of the government. This strategy is to strengthen the country environmental protection in the period of promoting industrialization and modernization.

To tackle the challenges and successfully implement the course of environmental protection, the strategy set out guiding viewpoints as follows:

- The National Strategy for Environmental Protection is a part of the National Socio-Economic development strategy, and serves as grounds for sustainable development of the country. Environmental protection investment means the investment for sustainable development.
- Environmental protection must be the task of the whole society, all the level of the authority, sectors, organizations, communities and all citizens.
- Environmental protection must be based on the strengthening of the state management, institutional and legislation capacities, along with the raising of awareness and consciousness of environmental protection stewardship among the people and the whole society
- Environmental protection is a constant and long lasting work. Pollution prevention must be viewed as the key solution in combination with pollution control and treatment, remedy of degradation and improvement of the environmental quality; the implementation of these activities must aim at the focal points and locations.

This national strategy defined overall objectives for environmental protection in Vietnam in the period 2001 – 2010 which include: (1) Continuing to control and prevent environmental pollution; (2) Protecting, conserving and sustainably using natural resources and bio-diversification resources; (3) Improving quality of environment in urban, rural and industrial areas. The strategy also points out major activities and fundamental task for environmental protection are pollution prevention and control, remedy seriously environmental pollution and degradation, protection and sustainable extraction of natural resources, and protection and improvement of environment at focal areas.

As an evident of increasing concern on environment in a new stage of economic development in the country, on November 15th, 2004, the Politburo of Vietnam Communist Party issued Directive No. 41-NQ/TW on Environmental Protection in the period of accelerated industrialization and modernization of the nation. After assessing the current status of environmental protection, the Directive pointed out causes for success and weakness, set out 5 guiding standpoints, 3 objectives, 2 specific tasks and 7 solutions for environmental protection. The Prime Minister has issued an Action Plan to implement this Directive. ***This significant Directive also firstly laid foundation for fiscal reform toward environmental protection and sustainable development in the country by stating that from 2006, to allocated at least 1 percent of the state budget expenditures annually for environmental protection.***

Besides the above mentioned guiding documents, the Prime Minister, MONRE, other ministries, sectors, People's Committees of provinces and centrally-affiliated cities has issued and conducted the implementation of several strategies, planning documents and action plans on the environment, among which are action plan on biodiversity, strategy on urban solid waste management to 2020, national plan on oil spill rescue, etc.

Various ministries, including Health, Construction, Transportation, Industry, Fishery, Agricultural and Rural Development, etc. have issued regulations and action plans on environmental protection for their sectors. People's Committees of provinces and centrally-affiliated cities have issued strategies, planning and action plans on environmental protection within their jurisdiction and according to guidelines from the central level.

Along with the issue of advocacy, policies and legislation, arrangement for their implementation has been given increasing attention. Many plans, projects, and models for preventing and coping with environmental pollution, degradation and incidents have been established.

3.2. Development of institutional system for environmental management

In 1993, the National Environmental Agency was established under the Ministry of Science, Technology and Environment (MOSTE) in order to exercise the state management of environmental protection activities throughout the country. By 1999, the National Environmental Agency had 9 divisions with 79 staffs. The Environment Management Division with an average of around 2-5 employees was also established in every province/city under the Provincial Departments of Science, Technology and Environment (DOSTE). Several districts and provincial towns also have a cadre for environmental management. The functional units for environment management normally attached to the Department of Science and Technology have been established in some line ministries and economic sectors.

Generally speaking, during the period 1992 - 2002 the capacity of environmental management institutions in Vietnam remains weak and disproportionate to the tasks. The environmental managers and regulators employed in the system have been deficient in both their number and qualification.

The establishment of the Ministry of Natural Resources and Environment:

The Resolution No. 02/2002/QH11 stipulating the list of ministries and ministerial bodies of the Government, including the Ministry of Natural Resources and Environment (MONRE) was passed by The National Assembly, the first session of its 9th Congress, on 5th August 2002.

The Ministry of Natural Resources and Environment was established on the basis of the merging of the former General Department of Land Administration, the former General Department of Hydro and Meteorology, the National Environment Agency of Vietnam under the former Ministry of Science, Technology and Environment, Vietnam Department of Geology and Minerals and the Institute of Geology and Minerals (both later ones transferred from Ministry of Industry) and the section of water resources management previously attached to the former Department of Water Resources and Dyke Works Management (under the Ministry of Agriculture and Rural Development).

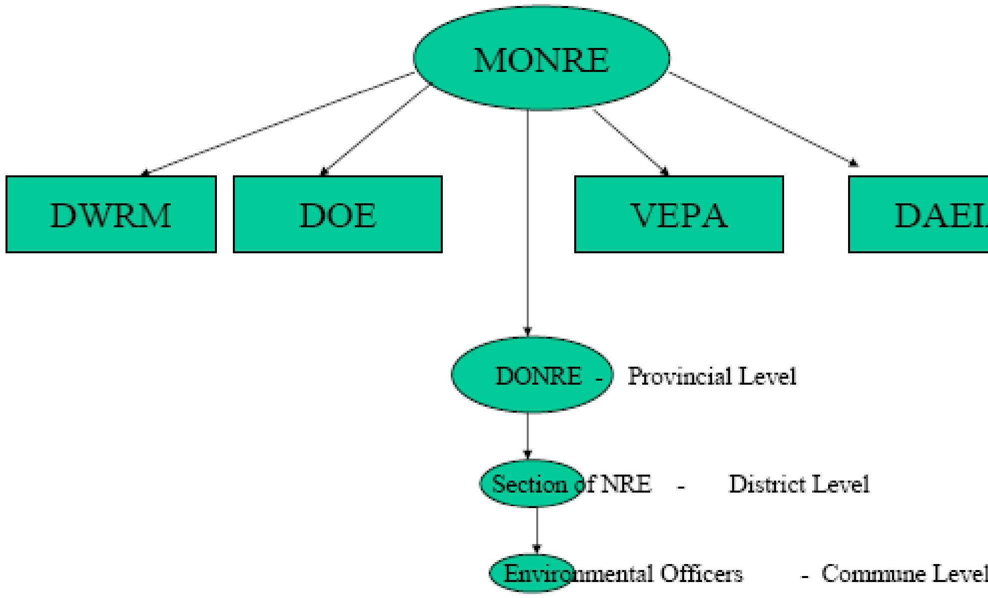
The Governmental Decree No. 91/2002/ND-CP was promulgated on 11 November 2001 to regulate the functions, tasks, powers and organizational structure of the Ministry of Natural Resources and Environment. The Ministry was also designated as the national focal point and the chairman of following national councils: for water resources, for the assessment of minerals volume, for overcoming the consequences of orange agents used by the Americans during the war time in Vietnam, for clean water supply and environmental sanitation.

The decision No. 45/2003/QD-TTg which is drafted by the Ministry of Natural resources and Environment and the Ministry of Home Affairs was enacted by the Prime Minister on 2 April 2003 regarding the establishment of provincial Departments of Natural Resources and Environment (DONREs). After the establishment of DONREs at provincial level, Divisions of Natural resources and Environment have been created at district level.

To consolidate the environmental management functions within the MONRE, in Sep. 2008, the Prime Minister has signed a decision No. 132/2008/QĐ - TTg to establish Vietnam Environment Administration (VEA) which marked a significant evolution in the process of environmental institutional development at central government level.

Since the establishment of the MONRE in 2002 and DONREs in 2003, the State management system on environment from central to local level has been gradually improving at four levels targeting on the integration of State management of environment with state management of natural resources. This also means that the previous gaps in environmental management at local levels, especially from provincial level downward have been gradually filled.

Along with the re-organization of function, task and organizational structure of Ministries and Sectors, the State environmental management bodies in ministries and sectors, have also been re-arranged and upgraded targeting at adapting to the new situation and organizational arrangements.



Environmental Management Institutional Structure

4. CURRENT STATUS OF GOVERNMENT ENVIRONMENTAL BUDGET AT THE CENTRAL LEVEL

This part is a review of the progress in central government budget annually as an evident of the keenness and efforts of the Government of Vietnam for integration of environmental concerns into socio-economic development plans of the country toward sustainable development.

4.1. The evolution of environmental integration in the state budget planning

Before the establishment of the MONRE, environmental protection function at the central level was a part of governmental function responsible by MOSTE and its National Environmental Agency. Due to this institutional structure, investment in environmental protection from the state budget accounts for app. 150 – 200 billion

VNDs each year, out of which 75% is budget for projects on basic investigation, infrastructure improvement, environmental protection and 25% is development investment budget for projects on environmental monitoring and analytical stations for Ministries and localities. The annual budget for environmental protection is taken from the item of recurrent expenses for science and technology in the state budget. Some capital sources for environmental related activities have been allocated from the category of economic development expenses.

Official development assistance capital for environment seems to increase annually but it accounts for a fairly small percentage of the total capital[2].

The establishment of the MONRE in 2002 has shown the strong effort of the government toward environmental protection in Vietnam. However, at that time, the government investment in environment has been limited as portion of the state budget allocated to environmental management and protection at both central and local levels has been low and inadequate. Financial resources invested in environment have not yet defined as a separate category of expenditure side in the State budget. This makes difficult not only for managing resources in a unified manner, but also for analyzing to calculate the share of environment in the total investment and for identifying the socio-economic effectiveness of environmental protection efforts.

In 2006, in order to have necessarily effective measures for implementation the Directive No. 41-NQ/TW of the Politburo of Vietnam Communist Party on Environmental Protection and the approved National Strategy for Environmental Protection until the year 2010 and vision toward 2020, is was approved by the National Assembly that from 2007, annually the Government will save at least 1% of the state budget expenditure for environmental protection activities and this portion would be increased in the following years depending on the budget financial resource capacity as well as the demand for environmental investment (see table 4.1; 4.2)

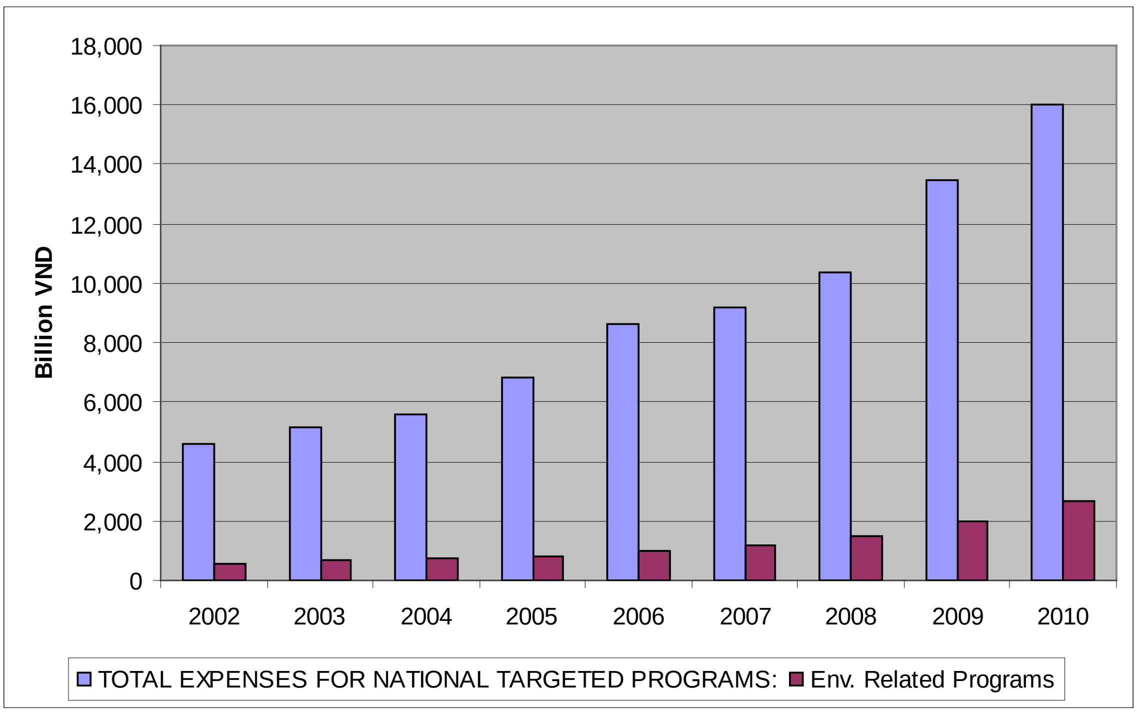
Thank to this important decision of the NA, the expenditure for environment has been increasing year by year from 2006 up to present. This increment is very supportive to meet with increasing demand on environmental protection activities need to be taken by the government authority at all levels.

Also from 2006, in the central budget expenditure by sector, the expenditure for environmental protection has been clearly defined as a separate item (see table 4.3). Also, there was a significant change in the budget allocation between central and local budget level (table 4.4) which bring more financial sources for

[2] State of Environment Report, Ministry of Natural Resources and Environment, 2005.

environmental protection activities at the local level which is considered as the most appropriate for addressing environmental problem and needs (Barde, 2002)

The environmental protection expenditure from the state budget is around 0.3 percent of the GDP of Vietnam. However, the government spending for environment in fact is higher since there is a part of investment which also closed related to environmental protection/improvement coming from government expenditure for development investment. These investments belong to the so called "national targeted programs"; among these programs, those most related to environment are reforestation program, the program on clean water and sanitary for rural areas, and the programs on energy saving and climate change coping recently initiated.



(Data source: Collected from annual State Budget of Vietnam, Ministry of Finance, Viet Nam)

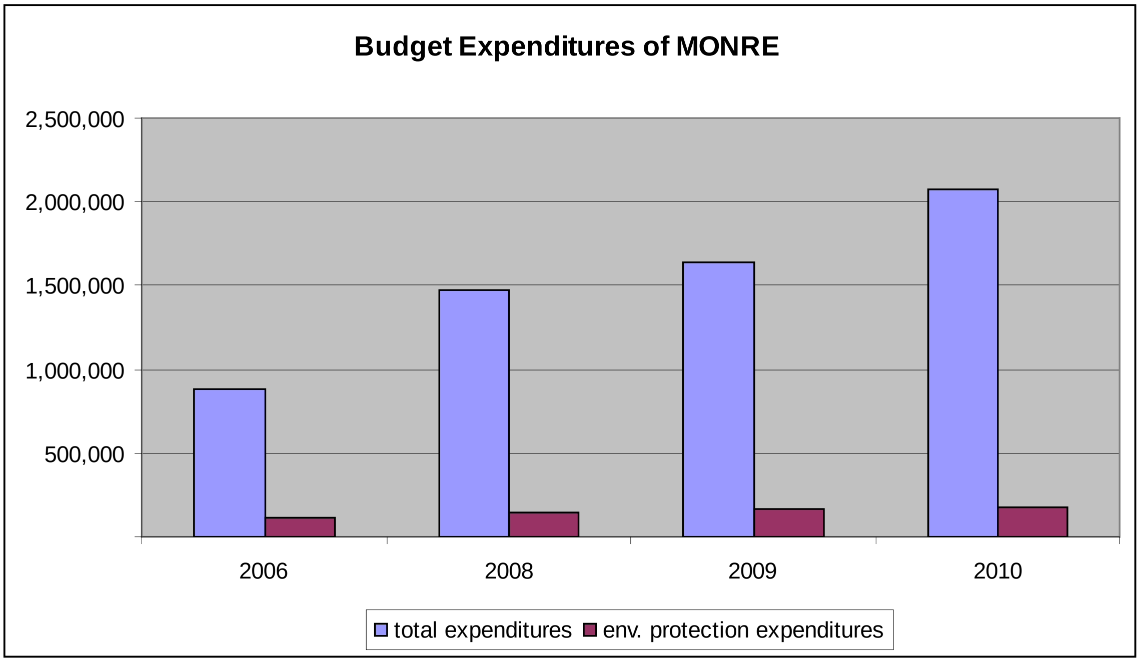

Budget Expenditures of MONRE
2,500,000
2,000,000
1,500,000
1,000,000
500,000
2006
2008
2009
2010
total expenditures
env. protection expenditures

Table 4.1: The state budget from 2000 to 2010 (in billion VND)

Year / Items	2000	2002	2003	2004	2005	2006	2007	2008*	2009*	2010*
GDP		535,762	613,443	715,307	839,211	973,791	1,144,014	1,478,695	1,813,000	1,931,300
Total State Budget Rev.	90,749	123,860	158,056	198,614	238,686	245,900	300,900	332,080	404,000	462,500
Total State Budget Exp.	108,961	148,208	178,541	221,792	279,873	294,400	357,400	398,980	491,300	582,200
Budget Deficit	-18,212	-24,348	-20,485	-23,178	-41,187	-48,500	-56,500	-66,900	-87,300	-119,700

*Budget planning

(Data source: collected from annual state budget reports, provided by Ministry of Finance, Vietnam)

Table 4.2: The State Budget Expenditure and Environmental Expenditure (in billion VND)

Items / Year	2000	2002	2003	2004	2005	2006	2007	2008*	2009*	2010*
GDP		535,762	613,443	715,307	839,211	973,791	1,144,014	1,478,695	1,813,000	1,931,300
Total State Budget Exp.	**108,961**	**148,208**	**178,541**	**221,792**	**279,873**	**294,400**	**357,400**	**398,980**	**491,300**	**582,200**
Science, Tech. & Environmental Exp.	***1,243***	***1,852***	***1,853***	***2,362***	***2,584***	***2,900***	***3,500***	***3,883***	***5,150***	***6,230***
% share in total Budget	***0.011***	***0.012***	***0.010***	***0.011***	***0.009***	***0.010***	***0.010***	***0.010***	***0.010***	***0.011***
% share in GDP		***0.0035***	***0.0030***	***0.0033***	***0.0031***	***0.0030***	***0.0031***	***0.0026***	***0.0028***	***0.0032***

(Data source: collected from annual state budget reports, provided by Ministry of Finance, Vietnam)

Table 4.3: CENTRAL GOVERNMENT BUDGET EXPENDITURES (in billion VND)

Year	2003	2004	2005	2006	2007	2008	2009	2010
Total budget expenditure	**152,051**	**151,707**	**199,284**	**214,558**	**272,515**	**252,229**	**314,544**	**370,346**
Science, Tech. & Env. Ex.*	1,351	1,819	1,924					
Environmental Protection Expenses				**500**	**530**	**580**	**850**	**980**

(Data source: collected from annual state budget reports, provided by Ministry of Finance, Vietnam)

Table 4.4: EXPENDITURE FOR ENVIRONMENTAL PROTECTION IN STATE BUDGET

Year	2006	2007	2008	2009	2010
Science, Tech. & Environmental Exp.	***2,900***	***3,500***	***3,883***	***5,150***	***6,230***
Of which					
central government budget	500	530	580	850	980
Local government budget	2,400	2,970	3,303	4,300	5,250

(Data source: collected from annual state budget reports, provided by Ministry of Finance, Vietnam)

Table 4.5: TOTAL EXPENSES FOR NATIONAL TARGETED PROGRAMS (in billion VND)

Year	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total expenses		**4,575**	**5,161**	**5,572**	**6,852**	**8,631**	**9,175**	**10,382**	**13,452**	**15,984**
Env. Direct Related Programs		***569***	***662***	***766***	***804***	***963***	***1,170***	***1,464***	***1,975***	***2,652***
Of which										
Reforestation	293	350	392	500	503	610	720	820	1,000	1,425
Safe water and sanitation		219	270	266	301	353	430	622	935	1,099
Energy Saving							20	22	40	61
Climate Change										68

(Data source: collected from annual state budget reports, provided by Ministry of Finance, Vietnam)

Table 4.6: TOTAL BUDGETS OF LINE MINISTRIES RELATING TO ENVIRONMENTAL PROTECTION (in million VND)

Ministries	2006		2008		2009		2010 (planning)	
	total expenditure	environmental protection expenditure	total expenditure	environmental protection expenditure	total expenditure	environmental protection expenditure	total expenditure	environmental protection expenditure
Agricultural and Rural Development	3,153,848	8,100	3,589,162	22,000	5,714,417	25,620	6,172,712	17,895
Transportation	8,944,175	5,500	8,509,123	12,990	8,844,539	7,820	10,327,159	12,416
Industry and Trade		16,100	1,137,105	18,250	1,387,760	19,400	1,644,003	18,860
Construction	1,848,410	10,000	807,356	9,420	884,027	9,500	1,437,291	8,800
Health	2,437,841	11,000	3,955,586	34,110	4,622,569	40,641	5,498,341	36,870
Education and Training	2,750,236	4,200	4,057,535	13,950	3,868,160	13,550	4,361,017	9,500
Science and Technology	402,915	2,700	579,839	3,000	1,011,815	5,430	933,120	5,500
Cultural. Sports, and Tourism	1,000,840	4,000	1,567,995	6,180	1,813,450	13,850	1,984,432	12,006
Natural Resource and Environment	880,479	112,000	1,473,931	150,000	1,641,443	165,000	2,073,650	180,000

4.2. Vietnam Environmental Protection Fund (VEPF)

4.2.1. Establishment and Evolution of VEPF

On June 26, 2006, the Prime Minister signed the decision to establish Vietnam Environmental Protection Fund (VEPF) which is functioned to mobilize capital from the State budget, funding sources, contributions, entrusted fund from organizations and individuals at home and abroad, aiming at providing financial supports for environmental protection activities nationwide. At the time of its establishment, the charter capital of VEPF was 200 billion VND financed by the statebudget.

VEPF is under the administration of MONRE and under the financial management of MOF. VEPF operates for non-profit purposes but ensure the retrieval of it charter capital and the coverage of managerial expenses by itself.

After two year since establishment, in August 2004 the fist environment project was approved to borrow.

In 2008, the Government decided to increase VEPF charter capital to 500 billion VND and its capital will be increasing up to 800 billion VND until 2010. The State Bank of Vietnam shall provide annual additional funds from the source of expenses for environmental operations to cover funding expenses for the environmental protection objectives and projects with a view to ensure VEPF's operating capital from the budget which is frequently maintained at VND 500 (five hundreds) billions. Modification of legal capital of VEPF shall be determined by the Prime Minister at the proposal of the Minister of MONRE and Minister of Financing Ministry

Apart from legal capital and annual additional budget provided sources of capital from expenses of environmental operations, VEPF also receives the annual additional operation sources of capital including:

- Environmental protection fees for wastewater, exhaust gas, solid waste, mineral exploitation and other environmental fees in compliance with the law.
- Amounts of compensation for environmental damages by the organizations and individuals paid to State budget in accordance with the law.
- Penalty for administrative breach within the area of environmental protection in accordance compliance with the law.
- CERs sale charges (CERs are the abbreviated names of Certified greenhouse Emission Reduction certificates, 1 CERs is specified as 1 ton of CO_2 respectively)

- The funds, supports, contributions and investment entrustments of the organizations and individuals at home and abroad.
- Other additional sources of capital in compliance with the law.
- Receiving annual additional sources of capital is implemented under instructions of the Ministry of Finance.

As stipulated by the government regulation, Vietnam Environment Protection Fund (VEPF) is responsibility to

- receiving capital sources follow regulations to make as the operation funds of VEPF, and
- providing financial support for programs, projects, natural conservation and bio-diversity operations, prevention and control pollution of national inter-disciplinary and inter-region pollutions, depression and settlement of local environmental problems but having sphere of large influence in the following forms: soft loan, capital loan interest support, capital loan guarantee for the environmental projects funded by credit organizations in accordance with the law.
- Funding for setting up and developing capital raise projects of the VEPF for implementation of objectives and operations of overcoming environmental pollution, coping with and overcoming consequences caused by environmental disasters; for programs, plans and projects in accordance with Decision of the Prime Minister; for organization of environmental awards, commendation and reward to respect the symbolic and progressive organizations or individuals as stipulated by Minister of MONRE; for environment protection projects, objectives as stipulated in organization and operation Regulations of VEPF.
- Co-sponsoring and soft-loans for the environmental projects that are conforming with criteria and functions of VEPF with financial organizations at home and abroad, Global Environment Fund (GEF), foreign environmental Funds, profession and local environment Funds designed for environmental protection funds as stipulated by the law.
- To organize appraisal and approval of level, period and funding method for the environmental protection projects and objectives using investment assistance source of capital from Vietnam's Environmental Protection Fund, in accordance with organization and operation Regulations of Vietnam's Environmental Protection Fund.
- To use unemployed funds without origin from the State budget and upon agreement of the funding organizations and individuals to purchase the public bond in compliance with the law.
- To organize registration, monitoring and management of Certified greenhouse gas Emission Reduction certificates (hereinafter referred to

CERs); to organize registration of receiving, dividing and selling CERs with CERs owners or CERs receivers; to collect CERs sale charges to cover expenses of charges collection; to spend on support of dissemination and propaganda operations of Clean Development Mechanism (hereinafter referred to CDM); to establish, set up, appraise and approve investment project documents in compliance with Clean Development Mechanism (hereinafter referred to CDM project); to manage and monitor implementation of CDM project and other CDM concerned purposes in compliance with the law, conducting price support for products of CDM project as stipulated by the law.

- To take deposit for environmental rehabilitation in minerals exploitation with organizations and individuals which are permitted to exploit minerals.
- To participate in financial coordination and management of the key environmental projection programs and projects that are assigned by Minister of MONRE and decision of the competent authorities.
- To carry out other duties to be assigned by Minister of MONRE.

4.2.2. Services provided by VEPF

4.2.2.1. Soft Loans/with offered rates

Targeted customers:

Object to be supported from VEPF are organizations and individuals who request and apply for soft-loans to implement projects, programs or activities on natural preservation and biodiversity preventing, combating and overcoming environmental pollution, deterioration and incidents of national, inter-sectional or inter-regional range, or dealing with environmental matters of a single locality but in large scale impact (hereinafter call investment project).

Loan criteria

- Criteria 1: Project rationale and justification.
- Criteria 2: Project effectiveness (environment, economy and society).
- Criteria 3: Project relevance to regulations of VEPF.
- Criteria 4: Project's replication.
- Criteria 5: Refundability.

Priority areas in financial assistance

- Waste treatment.
- Prevention and overcome environmental problem.
- R&D of environmental closely technology.

- Biodiversity conservation; and
- Environmental education/communication and sustainable development.

Priority projects in financial assistance

- Projects in list of the “Plan for strictly penalizing enterprises who caused severe environmental pollution” as promulgated in association with Decision No. 64/2003/QD-TTg of Prime Minister;
- Projects on waste treatment in urban areas, traditional villages and hospitals;
- Overcoming environmental problem;

- R&D of environmentally-friendly technologies;
- Protection and improvement of vulnerable ecological systems, especially wetlands, inland conservation areas and marine conservation areas;
- Preservation of gene sources and special, rare and endemic species;
- Environmental education at schools;
- Introduction and maintenance movements for communities to create naturally friendly customs and behaviors;
- Propaganda for environmental protection and sustainable development; and
- Environmental protection awarding.

Implementation

- Loan principles: Project investors must (1) use the loan only for the purpose that stated in the credit contract; and (2) refund in time.
- Project investors must meet but are not limited to these conditions: (1) be eligible for taking loans from VEPF; (2) have legitimate capability; (3) the project already completed in terms of investment and construction procedure as regulated by law; (4) the project plan has been appraised and approved by VEPF; (5) be able to refund by the deadline pledged in the credit contract; (6) have a certain percentage of corresponding capital to the loan and (7) have righteous method of loan guarantee.
- Loan level: Loan level in VEPF is introduced by Ministry of Finance and finalized by Director of VEPF in each circumstance.
- Loan duration: Duration of the loan depends on the capital capacity of VEPF, conditions of the project and refundability of project owner but not exceed ten years. Exceptions are defined by the Management Council.
- Interest rate: Interest rate for each case is determined by Director of VEPF according to law regulations but not exceed the ceiling rate defined by Ministry of Finance for soft loan.
- Loan assurance: Loan assurance is compulsory and on basis of a secured asset under the form of mortgage, pledge or guarantee by a third party.

Other loan assurance regulations are due to existing law. The case of loaning without assurance is determined by General Director of VEPF, after consulting Leaders of the Operation Body.

4.2.2.2. Assistance in Loan Rate:

Targeted customers

Organizations and individuals who are eligible for financial assistance of VEPF, borrowing capital from other credit institutions.

Implementation

- Funding for interest rate support is available once a year, based on the principal and interest paid for that credit institution, excluding the overdue debt.
- Project owners should meet but are not limited to these conditions: (1) Their projects have been complete, put into operation and refundable to the credit institution; (2) Projects are certified by national or local authorities that they contribute to the environmental protection effectively or help overcome environmental problems; and (3) Projects have not received any fund from VEPF.
- Assistance level and legal authorities to decide: Interest rate support can not exceed 50% of the interest rate offered by the credit institution and can not exceed the ceiling rate defined by Ministry of Finance for VEPF.
- Director of VEPF can decide which assistance level apply to a certain project; otherwise Chairman of the Management Council shall decide.

4.2.2.3. Funding and co-funding/finance and co-finance

Targeted customers

VEPF will financing for organizations, individuals who have programs, projects as well as activities in the field of environmental protection as follows:

- Communication, public awareness and education in environmental protection.
- Development, implementation projects that raising from VEPF to carry out activities in treatment, and over come problem of environmental pollution.
- For the programs, plans, projects under decisions issued by the Prime Minister;

- Awarding prizes aiming at praising distinguished individuals or organizations for their efforts in saving the environment under the Decision of Minister of Natural Resourses and Environment; or
- Investment project in environmental protection doings according to VEPF's regulations.

Selection criteria

- Programs, projects or activities are eligible if they are certified by national administration on environmental protection that they are qualified enough;
- Regarding environmental protection projects, project owner must have the corresponding capital of at least 50% of the total investment amount;
- Application files are accepted by VEPF and credit contracts are signed between two parties.

4.2.2.4. CDM

VEPF's responsibility in CDM

- Registration of Certified of Certificate Emission Reductions (CERs) and implement CDM projects after getting CERs from the CDM Executive Board.
- Supervision and management of CERs granted by the CDM Executive Board to CDM projects in Vietnam;
- Collection of fees from selling CERs, which are used to:

(1) cover expenses for fee collection;

(2) help promoting public information on CDM;

(3) formulate and approve CDM project documents; and

(4) subsidize products' price of CDM project in priority fields.

- Price subsidies for CDM project's products.

CERs registration:

Until now, four units have registered for CDM project named "Associated gas collection and utilization in Rang Dong oil field". They are Japan-Vietnam Petroleum Co.,Ltd; Conocophillips (UK) Gama Ltd; Petro Vietnam; and PetroVietnam Exploitation and Production Corporation.

Collection fees from CERs selling or tranfering to Vietnam:

VEPF has appraised the self-calculated fee of Japan-Vietnam Petroleum Co.,Ltd and Conocophillips (UK) Gama Ltd paid for "Associated gas collection and utilization in Rang Dong mine" project. The accumulated amount of collected fee is about 927,366 Euro for 2,357,768 CERs. The first collection of CER fees was in 2008.

4.2.2.5. Deposit to recover the mineral exploitation

Targeted customers:

- All organizations and individuals who are allowed to exploit mineral resources must deposit for environmental restoration at VEPF before taking any action;
- Organizations and individuals who are exploiting mineral resources but have not deposited for environmental restoration must deposit for environmental restoration at VEPF;
- Organizations and individuals who have investment, construction projects and are allowed by administrative state agency to exploit mineral resources in the construction areas do NOT have to deposit for environmental exploitation.

Aim and principle

- Objective of deposit for environmental restoration is ensure financial sources for environmental re-operation and recover after exploitation;
- The minium deposit is equivalent to real cost involved in recovering environmental losses after exploitation.

Practice of deposit

- If exploitation duration is less than three years, project owner has to deposit once. Deposit amount is 100% of anticipated cost for environmental recovery project approved by related competent agency.
- If exploitation duration is three years or more, project owner may deposit more than once.
- Deposit amount is regulated as such: For the first time of payment: if exploitation duration is less than 10 years, project owner has to pay 25% of the total deposit; if it is between 10 and 20 years, project owner has to pay 20% of the total deposit and if it is 20 years or more, project owner has to pay 15%.
- With the latter payments, project owner should pay the rest amount which is already divided corresponding to each year of exploitation duration that left.

- If it is possible to deposit in instalments, project owner can still choose to deposit once.
- If exploitation duration is extended, organizations and individuals who exploit mineral resources need to set up supplement project for environmental recovery and pay additional deposit;
- Interest yielded from the deposit is similar to flexible deposit rate in commercial banks, starting from the date of deposit;
- Organizations and individuals apply for deposit need to fill in the form "Request for deposit for environmental restoration in mineral exploitation", then attach required documents and send them to VEPF's office.

List of enterprises who deposited at VEPF:

1. Hai Phong cement company
2. Tuyet Vu Co., Ltd
3. Thuy Lieu private business
4. Cam Pha cement JSC
5. Coal-mining mill 790
6. One member Ltd company 91
7. One member Ltd company 86
8. One member Ltd company 45
9. One member Ltd company 35
10. Hong Thai Coal Co., Ltd
11. Quyet Thang VINACONEX
12. Sanh Chien Co., Ltd
13. Binh Hoa Co., Ltd
14. Hoang Hau Construction Co., Ltd
15. Thach Anh Co., Ltd
16. Khe Sim firm

4.2.2.6. Debt guarantee

In some specific cases approved by the Management Council, organizations and individuals take loan from other credit institutions are able to request debt guarantee from VEPF.

Targeted customers

- Projects appraised and agreed to be loaned by a credit institution can submit application for debt guarantee of VEPF;
- Financial plan and refund plan is endorsed by VEPF;
- Project owners need to prove assured asset which is approved by VEPF.

Implementation

- Guarantee level and legal authorities to decide

    - The guarantee level to a certain project can not exceed the loan amount;
    - The General Director of VEPF can decide which guarantee level apply to a certain case; otherwise the Chairman of the Management Council shall decide;
- Period for Dept guarantee
    - Debt guarantee duration is appropriate with the loan duration agreed by both project owner and the credit institution but can not break VEPF's regulations on loan duration;
- Fees of guarantee
    - An amount of fee need to be paid to VEPF and is equivalent to part of the guarantee amount in percent (%). Detailed fees are guided by the Ministry of Finance;
- Drawing of standby financing in debt guarantee
    - Annually, VEPF sets up a fund for debt guarantee in percent (%). It is part of the total guarantee and is used when the project owner fails to return the debt to the credit institution in time. If the fund is not used up by the end of a year, it will be transferred to the next year's fund. If the fund is used up before the end of a year, the Management Council will report to the Minister of Natural Resources and Environment and the Minister of Finance in order to testify before the Prime Minister. That amount of fund is decided by the Ministry of Finance;
- Set up the Risk Fund for debt guarantee
    - Annually, VEPF also sets up a fund for risk management of debt guarantee. It aims to cover the expenses paid to credit institutions that can not be refunded by project owner later. This amount is also ruled by the Ministry of Finance;
- Risk management and legal authorities to risk management:

When the credit institution requires debtor to refund in time while the project owner can not meet the requirement, VEPF will substitute to pay.

- After taking responsibility for debt guarantee, VEPF requests project owner to sign a covenant with VEPF about the the amount of money Vietnam Environment Protection Fund shall pay on behalf of the project owner, and at the same time, liquidate the assured assets to cover the expenses or prosecute a claim for damages if project owner intentionally violate his/her duties as mention in the guarantee contract with VEPF.
- The General Director of VEPF is responsible for consulting the Management Council about assured assets liquidation or prosecution a claim regarding law regulations.
- Risk management fund for debt guarantee is used when liquidation of assured assets can not cover the cost that VEPF paid to the credit institution on behalf of the project owner. In that case, the Management Council

should report to the Minister of Natural Resources and Environment and Minister of Finance in order to testify before the Prime Minister.

Application and procedure for debt guarantee is ruled in The regulations of operation of VEPF.

4.2.3. Statistics on Operational Results of VEPF at the end of 2009

Soft loans

Total amount lending out is approximate 350 billions VND for 92 environmental projects in the fields of:

- Solid waste treatment.
- Treatment of air pollutants from industrial and cement production factories.
- Wastewater treatment facilities.
- Socialization of domestic solid waste collection.
- Pollution treatment at rural areas.
- Energy saving and cleaner production projects.

Funding/Grants

VEPF funded to 99 projects with the total funding amount of 17.5 billion dongs for the following activities

- Environmental pollution after hurricanes, treating epidemic diseases ;
- Awarding to press on environmental protection activities
- Awarding prizes on environmental awareness contests.

Clean Development Mechanism (CDM)

- Collecting over 927 thousands Euro on CERs fees; registering CERs for 2 projects and providing funds of 600 million dongs to disseminating CDM and climate change.

Resource exploitation deposits: the first deposit was made on November 2008. Up to present, VEPF has received deposits of 42 industries which are worth 19 billion VND.

Development Cooperation

- VEPF has established collaborations with Danish Development Agency (DANIDA) in many environmental protection projects. A Program on Green House Effects Reduction has been developed in cooperation with Jetstar Pacific Airlines. Besides, VEPF has been closely working with other domestic projects such as the Project on Pollution Control in Developing Areas, the project on Efficiency of Energy Consumption in SMEs, the project on capacity development for water pollution control in Vietnam.

5. DESCRIPTION AND COMMENTS ON EXISTING TAXES AND CHARGES WHICH ARE DIRECTLY RELATED TO ENVIRONMENTAL PROTECTION PURPOSES

Facing to environmental pollution pressure and huge demand on environmental protection investment, in the recent years, Vietnam Government has shown great concerns on fiscal reform to serve environmental protection tasks. It is well recognized that the focus of economic tool package for environmental protection policies is environmental taxes and pricing mechanisms such as fees and charges. Legal basis for environmental taxes and charges has been clearly defined in the 2005 Environmental Protection Law (articles 112 and 113). Together with taxes and charges, other economic tools stipulated by the Law are deposit funds for natural resource exploitation, environmental protection funds establishing at both central and local governmental levels.

With the view to mobilize revenues from society for environmental protection work, since 2004, the Government has started imposing the first kind of environmental charge on wastewater. Up to present, there are 3 kinds of charges being applied directly for environmental purpose which are environmental protection charges for wastewater, solid waste, and mineral exploitation.

5.1. Environmental protection charge for waste water:

The charge has been applied from 2004 onward to organizations and household.

Objectives expected from charges collection are to limit the environmental pollution caused by waste water; to economically use clean water; and to create the funding source for the Environmental Protection Fund in protecting the environment and addressing the environmental pollution.

According to the regulation, Rates of environmental protection charges for waste water are prescribed as follows:

(1) For daily-life waste water, the environmental protection charge rates shall be "calculated in percentage (%) of the selling price of 1 m3 (one cubic meter) of clean water but must not exceed 10% (ten percent) of non- VAT clean water selling price. For daily-life waste water discharged from organizations and households which exploit by themselves water for use (except for households in

localities where exists no clean water supply systems), the charge rate shall be determined for each water user and based on the average clean water use volume per head in the commune or ward where water is exploited, and on the average supply price of 1 m3 of clean water in the locality.

(2) The environmental protection charge rates applicable to industrial waste water and calculated for each pollutant are prescribed as follows:

No.	Pollutant in wastewater		Charge rate (VND/kg of pollutant found in wastewater)			
	Pollutant	Symbol	Receiving environement A	Receiving environement B	Receiving environement C	Receiving environement D
1	Biochemical Oxygen Demand	A_{COD}	300	250	200	100
2	Suspended solid	A_{TSS}	400	350	300	200
3	Mercury	A_{Hg}	20.000.000	18.000.000	15.000.000	10.000.000
4	Lead	A_{Pb}	500.000	450.000	400.000	300.000
5	Arsenic	A_{As}	1.000.000	900.000	*800.000*	600.000
6	Cadmium	A_{Cd}	1.000.000	900.000	*800.000*	600.000

The collected charges are used for reinvesting to environmental protection projects, investing in construction of new and upgrading of sewerage system in the cities and provinces. In details, distribution of charge revenues as follows:

- 20% left for collection agencies to cover expenses relating to charge collection activities
- 40% remitted to state budget to add for operating capital of VEPF
- 40% contributed to local budget which is used for environmental protection, new investment projects, sewerage dredging, regular repair and maintenance of local water drainage systems.

5.2. Environmental protection charges for solid wastes:

In accordance to the government decree No. 174/2007/NĐ-CP dated on 29/11/2007, the charge has been officially applied since 2007 to solid waste (domestic, industrial and hazardous wastes) disposal by industries, businesses, and households.

The rates of charge are set as follows:

(1) For normal solid wastes disposal by institutions, businesses, industries: charges are not exceeding 40.000 VND per ton.

(2) For hazardous wastes, maximum charge is 6.000.000 VND/ton

Revenues are left to collection agencies and the rest for local budget.

5.3. Environmental protection charges for mineral exploitation:

This charge has been applied since 2008 by the government decree No. 63/2008/NĐ-CP dated on 13/05/ 2008. Charges are collected from natural resources exploitation activities on both metal and non-metal minerals, crude oils, and natural gas. Revenues from crude oils and natural gas exploitation are for state budget, and from other mineral exploitation left for local budget.

Besides, there are fees collected from petrol and other refined fuels. Although, these fees are not originally for environmental purpose, however, it can be classified as a type of environmental related fees/charges. The revenue are used for state budget.

5.4. Other taxes which have indirect environmental effect:

Although in the current tax policy, all the applied taxes have not carried environmental objectives, however, they do have some environmental protection incentives. In several types of taxes such as special consumption tax, business income tax, export and import taxes, there are some exemptions regarding environmental protection purposes. For example, environmental industries are subjected for only 10% business income tax compared to the normal rate of 25%. 100% tax exemption is applied for environmental equipment imported.

Environmental protection charges have positively affected to enhancing awareness of industrial community on the value of environment. Industries have been becoming familiar with a fact that environmental costs should be included in their production cost accounting process. Besides, environmental protection has contributed additional revenue to the state budget.   According to the statistics, the total revenue from environmental protection charges in 2008 is only 1.224 billion VND. Revenue from refined fuel is about 9000 billion VND, which bring total revenues from environmental related charges to 10.224 billions VND while the financial demands are very huge at present.

Regarding to the effects on pollution reduction and economical use of natural resource as stipulated by the objectives of charges, all the current applied charges have not yet met with the expected objectives. The amount of charge collected is very modest due to very low rate of charge and unreliable charge calculation in some cases. As a result, average charge level is much lower than pollution abatement costs, so that the current charge has not been an incentive which is strong enough to induce industrial firms applying pollution reduction measures. In other words, charge revenues have not been able to contribute to enhance pollution reduction effects in accordance to the "polluter pays principle".

6. FUTURE PROSPECTS OF ENVIRONMENTAL FISCAL REFORM AND SUGGESTIONS FOR ESTABLISHING GREEN BUDGETING IN VIETNAM

Up to present, most environmental charges are at very low rate, and the scale is very limited. Besides, there are other problems existing with currently applied charges such as poor design, weak incentive toward environmental protection.

From the beginning of 2010, the Ministry of Finance has been assigned by the Government of Vietnam to take the lead in preparing the first draft on Environmental Tax Law which is in the first round of discussions at the National Assembly meetings now. Many environmental charges currently applied will be amended in the coming time.

Although the allocation of 1% state budget to environmental expenditures has been firmly defined by the government, spending objectives, scope and principles for environmental activities should be clearly set out in order to ensure the efficiency and the effectiveness of the environmental expenditures.

The environmental expenditures thus may include such activities as basic surveys and construction supporting environmental protection. The disbursement of state budget to environmental activities should focus on the specific objectives including: management of wastes, mitigation and halting environmental pollution and deterioration, gradually handling environmental hot spots, improvement and enhancement of environmental quality.

REFERENCES:

Barde, Jean-Philippe (2000), "Environmental Policy and Policy Instrument" in *Principles of Environmental and Resource Economics: A Guide for Students and Decisions Makers*, edited by Folmer H. and H. L. Gabel, 2nd edition, Edward Elga, pp. 157 – 198.

Ministry of Finance, *State Budget Report*, 2002.

Ministry of Finance, *State Budget Report*, 2005.

Ministry of Finance, *State Budget Report*, 2006.

Ministry of Finance, *State Budget Report*, 2008.

Ministry of Finance, *State Budget Report*, 2009.

Ministry of Natural Resources and Environment, *State of Environment Report*, 2005.

Ministry of Natural Resources and Environment, *State of Environment Report*, 2006.

Ministry of Natural Resources and Environment, *State of Environment Report*, 2008.

ANNEX 1: STATE BUDGET REVENUE

No.	Items	Plan 2008	Estimates 2008	Plan 2009
A	B	1	2	3
A	**STATE BUDGET BALANCE REVENUE**	**323,000**	**399,000**	**389,900**
I	Domestic revenues	189,300	205,000	233,000
1	Revenue from sale of State - owned enterprises	63,159	64,131	72,982
2	Revenue from Foreign invested enterprises	40,099	40,953	51,499
3	Revenue from Non-state sector	38,347	40,618	46,597
4	Agricultural tax	82	76	42
5	Individual income tax	8,135	9,960	14,545
6	Tax on the transfer of properties	5,194	6,415	7,251
7	Gasoline fee	4,979	4,942	5,371
8	Fees and charges	4,889	5,698	7,324
9	Revenues from land, housing	21,792	29,024	24,539
	- Land and housing tax	*698*	*814*	*952*
	- Tax on land use right transfer	*1,974*	*2,820*	
	- Rental of land	*1,569*	*2,311*	*1,877*
	- Land use right assignment	*16,500*	*22,000*	*21,000*
	- Revenue from sale of State - owned houses	*1,051*	*1,079*	*710*
10	Others	1,937	2,510	2,166
11	Revenues from public land and assets at communes	687	673	684
II	Oil revenue	65,600	98,000	63,700
III	Revenues from import-export activities	64,500	91,000	88,200
1	Total revenues	84,500	121,000	121,200
	- Import - Export tax, special consumtion tax on Imports	*26,200*	*57,420*	*56,600*
	- Value added tax on import	*58,300*	*63,580*	*64,600*
2	Refunds for value added tax, collection management fees	-20,000	-30,000	-33,000
IV	Grants	3,600	5,000	5,000
B	**BROUGHT FORWARD REVENUE**	**9,080**	**9,080**	**14,100**
C	**UNBALANCE REVENUES**	**47,698**	**31,059**	**46,960**
D	**ON LENDING**	**12,800**	**12,425**	**25,700**
-	**TOTAL (A+B+C+D)**	**392,578**	**451,564**	**476,660**

STATE BUDGET EXPENDITURE

No.	Items	Plan 2008	Estimates 2008	Plan 2009
A	B	1	2	3
A	**STATE BUDGET BALANCE EXPENDITURE**	**398,980**	**474,280**	**491,300**
I	Development investment expenditures	99,730	117,800	112,800
	Of which: Capital expenditure	*96,110*	*110,050*	*107,540*
II	Repayment for debts and provision of grants	51,200	51,200	58,800
1	Domestic debt repayment	39,700	39,700	47,630
2	Foreign debt repayment	10,700	10,700	10,370
3	Provision of grants	800	800	800
III	Recurrent expenditures	208,850	262,580	269,300
	Of which:	-	-	-
1	Education and training	54,060		67,330
2	Health care	16,643		23,360
3	Population and family planning	615		710
4	Science, technology	3,827		4,390
5	Culture and information	2,440		2,740
6	Television and radio	1,420		1,560
7	Sports	880		1,320
8	Social security	35,793		52,931
9	Economic services	15,622		24,730
10	Environment protection	3,883		5,150
11	Public administration, Party and Unions	28,438		33,629
12	Good price subsidies under state regulations	763		930
IV	Oil subsidies	-	28,500	-
V	Contingencies	10,700	-	13,700
VI	Transfers to financial reserve fund	100	100	100
VII	Salary reform	28,400	-	36,600
VIII	Brought forward expenditure	-	14,100	-
B	**UNBALANCE EXPENDITURES**	**47,698**	**31,059**	**46,960**
C	**ON-LENDING**	**12,800**	**12,425**	**25,700**
-	**TOTAL (A+B+C)**	**459,478**	**517,764**	**563,960**

Local Budget Expenditure for Environmental Protection in 2009

Unit: Million VND

No	**Province/ Cities**	**Year 2009**
I	**Northen Mountain**	**271,936**
1	Hà Giang	11,901
2	Tuyên Quang	15,950
3	Cao Bằng	10,690
4	Lạng Sơn	14,300
5	Lào Cai	46,400
6	Yên Bái	13,373
7	Thái Nguyên	45,600
8	Bắc Kạn	1,800
9	Phú Thọ	35,200
10	Bắc Giang	21,469
11	Hòa Bình	18,892
12	Sơn La	22,620
13	Lai Châu	2,681
14	Điện Biên	11,060
II	**Hong River Delta**	**1,515,758**
15	Hà Nội	869,998
16	Hải Phòng	157,032
17	Quảng Ninh	82,362
18	Hải Dương	31,100
19	Hưng Yên	47,517
20	Vĩnh Phúc	93,600
21	Bắc Ninh	54,000
22	Hà Nam	17,004
23	Nam Định	71,620
24	Ninh Bình	28,175
25	Thái Bình	63,350
III	**Central Costal Area**	**390,366**
26	Thanh Hóa	70,367
27	Nghệ An	54,880
28	Hà Tĩnh	4,400
29	Quảng Bình	20,043
30	Quảng Trị	8,853
31	Thừa Thiên - Huế	5,523
32	Đà Nẵng	62,804
33	Quảng Nam	30,428

34	Quảng Ngãi	20,632
35	Bình Định	23,700
36	Phú Yên	9,045
37	Khánh Hòa	43,150
38	Ninh Thuận	12,440
39	Bình Thuận	24,101
IV	**Highland**	**126,078**
40	Đăk Lăk	58,845
41	Đắk Nông	13,519
42	Gia Lai	2,100
43	Kon Tum	19,406
44	Lâm Đồng	32,208
V	**South East**	**1,777,495**
45	Tp. Hồ Chí Minh	1,371,318
46	Đồng Nai	85,673
47	Bình Dương	97,454
48	Bình Phước	29,843
49	Tây Ninh	16,800
50	Bà Rịa - Vũng Tàu	176,407
VI	**Mekong Delta**	**332,203**
51	Long An	34,800
52	Tiền Giang	19,830
53	Bến Tre	13,222
54	Trà Vinh	12,428
55	Vĩnh Long	14,550
56	Cần Thơ	65,000
57	Hậu Giang	13,379
58	Sóc Trăng	23,164
59	An Giang	35,750
60	Đồng Tháp	30,740
61	Kiên Giang	36,850
62	Bạc Liêu	12,490
63	Cà Mau	20,000
	Total	**4,413,836**

(Data source: State budget planning Report 2009, provided by Ministry of Finance, Viet Nam)

Can Environmental Expenditure Support to fulfill the Environmental Protection Target[1]

Wu Jian, Ma Zhong
School of Environment & Natural Resources
Renmin University of China, Beijing, 100872

1. The environmental protection target

Although the environmental protection target in China's 10th Five-Year Plan (2001-2005) was not achieved, the 11th Five-Year Plan (2006-10) still set an ambitious environmental protection target for the following five years: namely, that total emissions of major pollutants would decrease by 10 per cent by 2010 over 2005. This was the first time that the central government set a compulsory environmental protection target.

2. The importance of environmental protection input

Many factors contributed to the failure of the environmental protection target in the 10th Five-Year Plan, but insufficient financial investment for environmental protection was undoubtedly an important one. To achieve the environmental protection target, China originally planned to invest 700 billion RMB for environmental protection,, which accounts for about 1.3% of planned GDP or 3.6% of planned total fixed assets investment. However, the actual growth rate of GDP is 9.5%, much higher above the anticipated 7%. Yet on this basis, investment in environmental protection was only 1.19% of GDP, and 2.84% of total investment in fixed assets during the period, both of which failed to achieve the planned target.

As data released by the State Environmental Protection Agency (SEPA) on the progress of environmental protection in the 10th Five-Year Period, we can see that, by year-end 2005, sulfur dioxide had only been reduced by 70% of the planned target. Among the planned 256 projects in "Sulphur Dioxide and Acid Rain Control Zone", only 54% were finished and operational. Among the 2,130 pollution treatment projects proposed in the National Environmental Protection 10th Five-Year Plan, only 65% of the projects were complete. This represented actual investments of 86.4 billion RMB, or 53% of the planned investments. By year-end 2005, the ratios of completed pollution treatment projects on the Huaihe River, Haihe River, Laiohe River, Taihu Lake, Chaohu Lake and Dianchi Lake, were 70%, 56%, 43%, 86%, 53% and 54% respectively.[1]There was clearly a problem of inadequate investment in environmental protection.

After an environmental protection target is set, the availability of financial resources becomes the most important factor in its achievement. Without funds or with funding

1 This paper is supported by "Excellent Talents Cultivation Program by Beijing Municipal Government 2007." No. PYZZ090513001705

shortfall, the environmental protection target cannot be achieved. Given that government set a compulsory environmental protection target for the 11th Five-Year Plan, it is essential to give serious consideration to the financial resources needed to achieve this target.

3. Questioning the measurement of *environmental protection investment*

During the past 20 years, investment in environmental protection in China increased from 47.642 billion RMB in the 7th Five-Year Plan, to 130.7 billion RMB in the 8th, 347.7 billion RMB in the 9th, and 838.8 billion RMB in the 10th. [2][3]The proportion of environmental protection investment in GDP increased from 0.68% in the 8th Five-Year Plan to 0.81% in the 9th, and 1.19% in the 10th (Since 1993, GDP data has been adjusted in the first general economic survey). The growth rate of investment in environmental protection during 10th Five-Year was 6% higher than that of GDP. The proportion of investment in environmental protection in GDP exceeded 1% for the first time in 2000, and reached 1.3% in 2005. The ratio for the following three years was 1.23% for 2006, 1.36% for 2007, and 1.49% for 2008.[4]

However, the increasing growth of investment in environmental protection does not reflect the real situation. Statistics on investment in environmental protection do not reflect China's overall expenditure on environmental protection. Firstly, this is because environmental protection activities have focused on pollution control, and so investment figures are mainly calculations for pollution control. They include investment in preventing pollution in newly constructed projects, investment in pollution control in existing plans, and investment in urban environmental infrastructure. Investment in ecological protection and capacity-building for environmental protection are not included, and so these figures do not fully reflect the overall status of investment in environmental protection. Secondly, for many years, the notion of "investment in environmental protection" only include capital investment expenditure, especially that for construction of pollution control projects, but not consumptive expenditure by government or operational costs paid by the private sector. Therefore, we should carefully assess "environmental protection expenditure", especially when compared with GDP, as this concept can better reflect gross domestic expenditure on environmental protection.

The current statistics for investment in environmental protection also obscure inadequate expenditure on environmental protection. People would like to use the concept of the "proportion of environmental protection investment in GDP" to characterize the level and intensity of environmental protection investment. In our opinion, these current calculations of investment in environmental protection are mainly part of investment in fixed assets. The proportion of investment for environmental protection within all investment in total fixed assets, and its growth rate, would better reflect the actual situation. For example, investment in environmental protection reached 838.8 billion RMB, and an annual growth rate of 15.57%, in the 10th Five-Year Plan, which was higher than 9.5% of GDP's growth rate. However, it was still significantly lower than the 19.62% growth rate in investment in fixed assets during that period. Since investment in fixed assets grew more rapidly than that for environmental protection, the proportion of environmental protection investment in fixed assets declined during the 10th Five-Year Plan, or 2.97%, 3.13%, 2.93%, 2.71%, 2.70% in each respective year. [5] Even in the 11th Five-Year Plan, the proportion was 2.34% for 2006, 2.47% for 2007, and 2.60% for 2008, with no evidence of an obvious increase. [6] This highlights the problem that investment in environmental protection does not equal the speed of fixed assets investment. China is now experiencing rapid industrialization and urbanization, and a low rate of growth for investment in environmental protection vs high speed of investment in fixed assets means that economic development is leaving more debts in environmental protection investment.

4. Concerning government environmental expenditure

4.1 Government's responsibility for environmental protection

To fulfill its environmental protection responsibility, the Chinese government needs to allocate appropriate fiscal resources. The government has attached great importance to environmental protection by declaring environmental protection to be a national basic policy. However, since the *Environmental Protection Law of PRC (Trial version)* was promulgated in 1979, government has not included a specific category for environmental protection in the national fiscal budget for almost 30 years. This means that a stable and reliable fiscal resource designated for environmental protection to fulfill the government's responsibility in this area was lacking.

Fiscal expenditure on environmental protection has special status and roles In the environmental protection capital market. First, it establishes the capacity for reliable environmental monitoring and supervision which can enforce and guarantee that all levels of government, industry or individuals fulfill their own responsibilities. Second, it facilitates to channel social capital into environmental protection. Third, it serves as an instrument to balance regional disparity, which is a key responsibility for the central government. Environmental fiscal expenditure is one of the most important measures which government can employ to fulfill its environmental protection responsibilities.

4.2 Mis-understanding the polluter-pays principle

What is the government's financial responsibility in environmental protection? On this issue, the principle of "polluter-pays principle" should not be an excuse for the government to ignore its financial responsibility for environmental protection. According to this principle, responsibility for environmental protection has, for many years, mainly rested with local governments, which have then been transferred to firms (pollution sources). In many cases, the pollution sources were unable to treat the pollution or found ways to avoid undertaking treatment. This was exacerbated by lack of local government supervision or even collusion between local government and these firms. The polluter-pays principle is reasonable in principle, but fails in implementation.

Therefore, we should not take an *ex parte* understanding of the polluter-pays principle. In particular, we should not ignore a simple truth: for the extensive existing of externality in environmental protection, polluter-pays principle won't play automatically. The polluter-pays principle does not mean that government can escape its financial responsibility for environmental protection. The government has to correctly use its financial instruments to correct market and institutional failure, and to create mechanisms and external conditions for the polluter-pays principle to take effect.

4.3. The pan-market tendency of environmental protection

The commercialization of environmental protection can definitely lighten the financial burden of government. However, over-emphasizing the functions of the market and ignoring the role of government in correcting market failure and creating these markets will lead to failure to achieve both environmental protection targets and economic efficiency.

Let us take the construction and operation of environmental infrastructure as an example. Even where environmental infrastructure is a public-owned facility, the entry of private capital into this sector will not alter its original motivation of profit seeking. When there is regional disparity, private capital will inevitably rush into regions where charges for environmental services are high, and so can guarantee high profits. Over-concentration of capital and capacity in developed regions will eventually exacerbate regional imbalances in pollution treatment capacity. For instance, sewage treatment investment in China is mainly concentrated in wealthy cities that located in the lower reaches of major rivers or along the developed eastern coast. However, the sewage treatment ratio is still very low in middle and small-scale cities located along the middle and upper reaches of rivers, and in western China. Such an investment pattern would do little to overcome the worsening tendency of water quality in the whole water basin, despite rapid growth in overall investment. Therefore, environmental protection requires government to use its fiscal investment policies to counter market forces or correct market failures, to channel capital into environmental protection according to the requirements for meeting the environmental protection target.

The state must be very cautious in privatizing environmental utilities. Actually, governments in many countries recognize the political sensitivity of public environmental industry, which may create environmental incidents and even turn into political crises. Our central government should heed the "pan-marketing" tendency of the environmental public utility.

4.4 Competition among public sectors

Environmental protection was only officially added to the 2007 government national budget category in 2006. As a relatively new government department, Environmental Protection has a rather weak standing in the public fiscal system. When allocating financial funds, the government generally focuses on the old powerful departments and overlooks Environmental Protection.

Allocation of fiscal funds among departments or sectors is sometimes driven by some particular urgent issues or emergency. As the priority for state financial expenditure changes, environmental expenditure would become unsustainable or even dissipated without achieving the expected environmental effects. For instance, the financial investment for the Slope-land Conversion Program (SLCP) was adversely affected after the fiscal priority of the central government changed to focusing on rural fiscal reform.

5. Ensure sufficient expenditure to achieve the environmental protection target

5.1 Keep increasing overall environmental protection expenditure

Since the target for environmental protection in the 11th Five-Year Plan was compulsory, it required increased investment in environmental protection. At the same time, the worsening environmental situation , growing marginal cost of pollution treatment, increasing requirements for environmental goods in response to increasing incomes, all required China to spend more on environmental protection.

5.2 Measure the intensity of environmental expenditure

Current statistical calibrations for environmental investment do not reflect the real environmental protection efforts and intensity in China. Total environmental protection expenditure should be calculated according to different financial sources in order to clearly reveal the financial contribution of different funding entities, including central government, local government, private sector, NGO, etc.

5.3 Clarify financial responsibility of different subject

The pollution control responsibilities of enterprises are relatively clear, but strengthening government capacity to undertake environmental monitoring and supervision is essential to ensure that enterprises invest in environmental protection as they grow. The environmental responsibilities of government should be defined according to the nature of public goods and area affected by environmental problems. Those environmental problems which have limited in a specific scope of jurisdiction of administration, are local environmental services and taken charge by the local governments. If the effect across the jurisdiction, or is even national, it’s national public goods, which should be taken charge by the central government. The environmental duty of central government mainly focuses on cross-provincial or intergenerational environmental issues. Given the large regional differences in economic development within China, the central and provincial governments should assist local governments, and particularly county governments in poor area via fiscal transfer, to first allocate funds for environmental protection management and environmental monitoring and supervision. This would help ensure that environmental protection departments can perform their regular administrative functions.

It is essential that funding for environmental protection should stable and sustainable rather than speculative. Economic fluctuations and macro economic adjustment should not affect the sustainability of national environmental fiscal policies. Financial expenditure for environmental protection should be long-term, sustainable, and stable.

References：

[1] Chinese Academy for Environmental Planning. “Analysis on accomplishment of the Tenth Five-year Environmental Protection Target”. SEPA Press Meeting , April 12, 2006.

[2] Wang Jinnan, Ge Chazhong, and Yang Jintian. *Environmental Investment and Financial Strategy [M].* Beijing, Environmental Science Press, 2003. pp. 38-39.

[3] SEPA. *National Environmental Statistical Bulletin* (1995-2005). Beijing, Environmental Science Press

[4] SEPA. *National Environmental Statistical Bulletin* (2006-2008). In 2008, SEPA was renamed Ministry of Environment Protection (MEP)

[5] National Bureau of Statistics of China. *National Economic and Social Development Statistical Bulletin of PRC in 2005*. February 28, 2006

[6] National Bureau of Statistics of China. *National Economic and Social Development Statistical Bulletin of PRC.* (2006-2008)

Consumption Analysis for Organic Cotton Products in Taipei, Taiwan

Wan-Jiun Chen[1], Yi-Lun Hsieh[2]

【Abstract】 Traditional cotton cultivation and manufacturing uses large amounts of pesticides and chemicals, and so organic cotton products offer the opportunity for global environmental protection. However, the limits demand for organic cotton hinders its development. This study establishes the foundations for development of Taiwan's domestic organic cotton products by extending consumer sovereignty through consumer analysis. Taiwan is a newly industrialized economy and organic cotton products in Taiwan are in the early stage of the life cycle of a product, not yet mature in their consumption. The population of consumers for organic cotton products is rather small, but Taipei is the center of the developing consumption of organic products for Taiwan. This study investigates consumer behavior of those consumers who have previously purchased organic products in Taipei by analyzing consumer characteristics. Several results are drawn from this study. (1) Accessibility to information. The main reason people do not purchase organic cotton products is a lack of understanding, and increasing understanding will effectively increase the willingness to purchase. (2) Reliability of certification. Certifications, labeling, place of production are important for consumers' purchasing decisions, in addition to the common factors of prices, and style for apparel. (3) Non-linear-income-determination.

There is a non-linear relationship between consumer income and the willingness to purchase organic cotton products. (4) Gender. The purchase proportion of women is higher than that of men, which is consistent with the truth of clothing in general. (5) Religious. Since Buddhists in Taiwan are more concerned about environmental issues, they purchase more organic cotton products than people of other religious. (6) Information confidence. Purchasing decisions are mostly affected by information provided through relatives and friends, rather than advertisement on media. (7) Type of store. Consumers tend to purchase organic cotton commodities in physical organic shops rather than from web-shops due to the perceived reliability. Conclusively, the length of producing process of organic cotton products is rather longer than other agricultural organic products such as rice, tea or coffees. The labels of organic cotton are complicated. Rather than merely relying on the international certification institute information that current Taiwan's importers currently provide, Taiwan's domestic certification authority should develop and provide reliable certification information in detail and inspect more regularly. Media and advertisement can provide knowledge about organic cotton products and reliable information for purchasing decision is mainly from relative and friends. Therefore, education by media, reliability from local certification and promotion from customer satisfactions is likely to expand the market scale of organic cotton products in Taiwan.

Keyword: organic cotton, consumer behavior, environmental protection, Taiwan

[1] Corresponding author: Associate Professor, Department of Economics, Chinese Culture University, 55 Hwa-Kang Road, Yang-Ming-Shan, Taipei, Taiwan. Phone: 886-2-28610511, Fax: 886-2-28625229, E-Mail: cwj@faculty.pccu.edu.tw

[2] PhD student, Department of Economics, Chinese Culture University, Taipei, Taiwan.

I Introduction

Historically, cotton is the main fiber used in the world. It has been a source of fiber for textiles for thousands of years in the regions of India, Egypt, Peru and a mechanized textile industry developed in the Industrial Revolution. Cotton now provides about half of all global fiber requirements (Myers and Stolton, 1999). Its cultivation and manufacture continue to play a very important role in the economies of the developing and newly industrializing countries. After World War II, chemical insecticides, pesticides, defoliants and fertilizers were used in cotton cultivation to increase yield world-widely (Forsythe, 1980; Ridgway et al. 1983).

Cotton is considered the world's 'dirtiest' crop due to its heavy use of the most hazardous pesticides to human and animal health. It covers 2.5% of the world's cultivated land yet uses more than 16% of the world's insecticides, and more than 10% of the world’s chemical pesticides, more than any other single major crop (E.J.F., 2007). It is also estimated that only 0.1 % of these chemicals reach the targeted pests, with 99.9 % dispersing into the soil, water and air. These chemicals directly increase the health risk of the cotton cultivation to farmers and all human beings. Many of these chemicals can cause cancer, birth defects and/or nervous system damage (E.J.F., 2007). The death rate due to local food contamination by pesticides is very high in Senegal and Benin, the two main cotton cultivation areas of Africa (Ferrigno et al., 2005). In addition, the manufacturing process of cotton textiles uses various kinds of chemicals which also degrade the soil contaminate surface and underground water, harm the environment and affect human health.

Organic cotton production is important to the long-term health of the Earth. Due to the many problems in conventional cotton production to support a healthy environment and sustainable human development, organic cotton production emerged. Organic cotton production involves issues of conversion to organic, crop rotation, crop varieties, seed treatment, soil fertility management, pest and disease management, harvesting, and manufacture (Elzakker, 1999). Organic cotton products are environmental friendly, and do not harm the cotton farmers. The primary difference between organic and conventional cotton products is in the methods used to grow and manufacture them (Eyhorn, et al. 2005). Organic cotton products are produced using natural methods without synthetic chemicals, including synthetic fertilizers, pesticides and defoliants in cultivation and various materials in the textile manufacture process.

There are many organic cotton certification organizations in the world, and a common certification standard is difficult due to: (1) the long distance of production processes, (2) varying places of cultivation and production world-wide and (3) different manufacturing methods.

The current market share of organic cotton products in the textile market is small, though it is expanding rapidly (Tean, 2007; Lucas, 2007; Wilson, 2004; Menon, 2003). According to the Organic Exchange Organization (2010), global organic cotton production increased 53% in 2006 and 152% in 2007. The top ten organic cotton producing countries in 2006 were Turkey, India, China, Syria, Peru, the United States, Uganda, Tanzania, Israel, and Pakistan (in order by rank). Nearly half (44.9%) of the organic cotton was grown in the Middle East (Turkey, Syria and Israel), while approximately one-third (32.9%) of organic cotton was grown in Southeast Asia (India and Pakistan).

Organic cotton is often sold to the conventional market since the market for organic cotton is saturated (Speer, 2005). By the principle of consumer sovereignty (Jodlbauer, 2008), increasing consumer demand is the essential factor to expand the organic cotton market share and further improve the environment and human health. Organic cotton use can be effectively increased on the demand side. Purchase characteristics and behaviors of current and potential consumers are the key to promote and increase demand. To get increased benefit from the consumer side, it is possible to rely on the producers' interest in providing products sustainably produced. If the demand for organic cotton fiber can increase, more cotton farmers and manufacturers will convert to organic production to meet the consumer demand.

International cotton prices have followed a long run decline. The reasons for the decline of cotton prices are similar to those for price declines in most primary commodities: reduced costs of production due to technological improvements, slow demand growth, and strong competition from chemical fibers. However, organic cotton products have the potential to be produced more efficiently and in much more cost-saving manners. Nimon and Beghin (1999b) found a price discount for the "no-dye" label in the U.S. apparel market, which reflects the cost savings resulting from the simplified production. They also found no evidence of heterogeneous pricing for the organic attribute by U.S. organic-apparel firms.

In fact, demand for organic cotton is not as strong as for organic foods since the consumer health feed-back mechanism of organic foods is typically more sensitive to the associated chemical contaminations. With organic cotton products, which are generally worn, the consumption is highly and directly related to concerns for the environment. Here, the consumer health feed-back mechanism is less sensitive.

A certification label informs consumers that the commodities were produced according to certain criteria. Consumers of clothing must pay attention to a host of factors before they make their purchasing decision. Adding to that already congested list, information on whether cotton is organic may increase the complexity.

To clarify consumer behavior in purchasing organic cotton products, this study investigated organic cotton product consumption behavior in Taiwan. This can provide organic product producers and sellers further insights about their potential customers, which may help develop better ways to market their products, and ultimately to significantly reduce the chemicals used in the earth and to increase the environmental health.

II Organic Cotton Consumption and Production in Taiwan

Organic farming and produce have grow rapidly in popularity and in recent years numerous organic stores and restaurants have sprung up across Taiwan, testifying to the growing public awareness of the health and environmental benefits of organic food and farming. In Taiwan, organic cotton products are promoted and advocated by religious and environmental protection groups, such as Liren Cooperation and the Homemaker’s Union and Foundation, and consumption began with small specialty groups.

The apparel manufacturing industry is an important sector for Taiwan’s economic development. Since Taiwan’s humid sub-tropical weather is not suitable for cotton cultivation, cotton for manufacture is imported. Organic cotton was introduced into Taiwan a few years ago, and it was first formally advocated in the first "Taiwan International Organic Fashion Fair” exhibition, held in 2006 at the Taipei World Trade Center. A series of environmental friendly textiles that supported environmental protection were then introduced in the “2007 Taipei Innovative Textile Application Show”. Dozens of Taiwan’s local producers of organic cotton products and import agents participated in the second "Taiwan International Organic Fashion Fair” exhibition of 2007. A series of apparel brands launched organic cotton products for sale in both physical stores (both department stores and boutiques) and network stores.

This study first conducted a focus group interview of Taiwan’s local textile firms in the second "Taiwan International Organic Fashion Fair” exhibition in 2007 (Hsieh, 2008). According to the interviews, finished organic cotton products were initially imported to Taiwan. Then to reduce production cost and retailing price, cotton and semi-finished products were imported for local manufacture from the U.S., Turkey, South America. The finished organic products are mainly imported from the U.S., Turkey, South America, Japan and Germany.

(Figure 1 Production chains of organic cotton products in Taiwan

Source: Organized from the information of focus group interviews for this study)

III The Methodology and the Survey

This study applied EBM consumer behavior analysis process (Engel, Blackwell and Miniard, 1995) to analyze the consumer behavior of organic cotton products in Taiwan by conducting a consumer interview survey. This section illustrates the theoretical methodology and the design of the survey.

(I) The methodology

The survey of consumer behavior was usually designed by questions of Whether, What, Why, When, Where and How (Walters and Gordon, 1970). The EBM consumer behavior analysis process was initially proposed by Engel, Kollat and Miniard in 1968 and amended by Engel, Blackwell and Miniard in 1986. The EBM process is based on the assuming that the consumption decision is made by a continuous process (input, dealing, and then output), reflecting the flow, dynamic and complete features of consumer behavior. Consumer decisions are made under the composite effects of multiple factors. There are four main components in EBM process. (1) Information input: internal and external information. (2) Information processing: consumers may contact, concentrate on, realize, accept, and retain the information. (3) Decision process: the EBM decision process is separated into the five stages of ensure demand, search information, assess alternatives, make purchase decision, and assess after purchase. (4) Influential factors: the two categories of influential factors are individual and environmental factors. Individual factors include motivation, knowledge, attitude, personal features, standard value, and life style. Environmental factors include culture, social class, family, reference groups, and circumstances.

In this study, the influential factors of consumer behavior are designed on the theoretical basis of the EBM decision process and collected by categorical count data. Since the numbers of observations occurring at each level of the variables are collected, the χ^2 test of independence was applied. The null hypothesis and alternative hypothesis of the χ^2 test are below.

$$H_0: independence \quad in \quad different \quad groups$$
$$H_1: not \quad independence \quad in \quad different \quad groups$$

(Figure 2 Structure of EBM consumption behavior

Source: Amended from Engel, Blackwell and Miniard, 1995, p.237)

(II) Survey

Since few people in Taiwan have purchased organic cotton products, in sampling from the total Taiwanese population, it is difficult to screen out the organic cotton consumers. Instead, this study uses the organic food consumers as the study population, assuming that the consumers of organic food are potential consumers of organic cotton products. Compared to consumers who have never purchased organic food, organic food consumers are much more likely to consume organic cotton products, with higher understanding and acceptations. Taipei, the largest city in Taiwan, is a pioneer center for organic cotton products. Therefore, this study interviewed the organic food consumers at randomly selected organic stores in Taipei. In this paper, the organic foods, the organic food consumers, the organic cotton products and the organic cotton product consumers are abbreviated by OF, OFC, OCP and OCPC respectively, hereafter. On the basis of EBM consumer behavior and Taiwan's consumption reality of organic cotton products, the survey was designed to collect consumption information to answer the following questions.

Question 1: How does the understanding of OCP affect the OCPC purchase decision?

Question 2: For the OCPC population in Taiwan, what is their purchasing frequency, average expenditure per purchase, most frequently purchased items, and the items that need to have their style improved?

Question 3: What are the reasons that OFC fail to purchase OCP in Taiwan?

Question 4: For consumer conceptions of OCP, consumer concerns when purchasing and the consumers' clothing habits, Likert's scale, and the χ^2 test of

independence are used to answer the following questions:

(1) How do the consumer conceptions of OCP affect the OCPC purchase decision? Is there difference between OCPC and OFC?

(2) What are consumer considerations that affect the OCPC purchase decision? Are there differences between OCPC and OFC?

(3) How do the consumer clothing habits affect the OCPC purchase decision? Are there differences between OCPC and OFC?

Question 5: What are the main channels of OF information, main sites of OF purchase and years of OF consumption? Are there a difference between OCPC and non-OCPC?

Question 6: Does OCPC purchasing vary among consumers of different demographic characteristics?

Question 7: Does the OCP and OF purchase behavior differ among OCPC?

The structure of the interview questionnaire is shown in Figure 3. The interviews were conducted with the following sequential steps.

(1) Introduce the purpose of the interview.

(2) Screen out the OFC to ensure that all of the respondents had previously purchased OF.

(3) Ask all of the respondents their OF consumption behavior.

(4) Ask if the respondents have ever purchased OCP.

(5) Ask about the consumption behavior for respondents that had previously purchased OCP and ask about the reasons for not purchasing OCP for those respondents who had not previously purchased.

(6) Ask all the respondents for their demographic variables.

This study conducted a focus group interview by including local OCP producers and import agents participating in the second "Taiwan International Organic Fashion Fair" exhibition in 2007. Based on the information drawn from focus group interview, a draft questionnaire was designed to cooperating the reality of Taiwan's OCP industry and the theory of EBM consumer behavior. A series of intensive pilot interviews were conducted from September to October, 2007 to amend the questionnaire for wording, logistics, and structure. A formal interview was conducted in October to November in 2007 by interception sampling. The interviews were held in randomly selected organic stores in Taipei. A totally of 660 OFC were randomly selected for interviews, in which 635 answered and 25 refused to answer. Of these, 394 effectively completed the questionnaires (a effective response rate of 62.05%), of which 105 had purchased organic cotton products and 289 had never purchased them. The error is 4.94% (controlled under 5%). The sample is reliable since the coefficient of Cronbach-α is 0.6.

(Figure 3 Structure of interview questionnaires)

IV The Results

Based on the information derived from 394 effective samples (where 105 had purchased OCP and 289 had not), the analysis results are demonstrated in the order of the questions mentioned before.

Question 1: How does the understanding of OCP affect the OCPC purchase decision?

Insufficient knowledge of OCP can result in a failure for the OFC to purchase OCP, as evidenced by the distribution frequency and the χ^2 test in Table 1. Most of the OFC failed to purchase OCP were in the groups of "had never heard of OCP" and "had heard of OCP but did not understand very well." Most of the OFC that purchased OCP were in the groups of "understand OCP very well" and "understand OCP well". Thus if the respondents have more knowledge about organic cotton, they are more likely to purchase OCP. The results suggest that the frequency of OCP purchase will dramatically increase after the consumers comprehensively understand the knowledge concerning with OCP.

(Table 1 OCP purchase decisions and knowledge of OCP)

Question 2: For the OCPC population in Taiwan, what is their purchasing frequency, average expenditure per purchase, most frequently purchased items, and the items that need to have their style improved?

OCPC consumption behaviors are analyzed based on the data from the 105 observations of OCPC. The yearly consumption frequency of OCPC almost reaches 5 times, and the purchases often occurred 2 to 3 times per year. The expenditure of a single purchase is usually under 7,000 NTD, often between 1,000 to 3,000 NT, and very rarely over 10,000 NTD. The items that most often purchased are towels, socks and underwear. The items that most need to have their styles increased are towels, underwear, beddings and shirts.

(Table 2 Distribution of OCP consumption in Taiwan)

Question 3: What are the reasons that OFC fail to purchase OCP in Taiwan?

Tables 1 and 3 indicate that failing purchase by the OFC is mainly due to a lack of relevant knowledge for OCP, including its existence, its background, and its characteristics. The reasons for failing to purchase OCP ranked by response frequency are “never heard of it”, “do not understand it” and “lack choices and few styles”. Price is not often the reason for not purchasing, nor is aversion by family members. Hence, to increase the exposure of OCP in the media can effectively increase the public's understanding. An implication assertion can be drawn here. To provide the public sufficient relevant information and to improve the styles in OCP items can effectively increase both of the market share of OCP and the scale of OCP production simultaneously. Thus, the public and the firms may more possibly benefit from the economy of scales.

(Table 3 Frequency of reasons for failing to purchase OCP among Taiwan's OFC)

Question 4: For consumer conceptions of OCP, consumer concerns when purchasing and the consumers' clothing habits, Likert's scale, and the χ^2 test of independence are used to answer the following questions:

(1) How do the consumer conceptions of OCP affect the OCPC purchase decision? Is there difference between OCPC and OFC?

(2) What are consumer considerations that affect the OCPC purchase decision? Are there differences between OCPC and OFC?

(3) How do the consumer clothing habits affect the OCPC purchase decision? Are there differences between OCPC and OFC?

This study used a Likert 1-to-5 rating scale to judge the level of consumer concepts toward OCP, consumer purchase features and consumer clothing habits. Each respondent was asked to judge each item on a 1-to-5 response scale to tell what the consumers believe, and how favorable each item is. The 5 scales are:

1. *= strongly agree (favorable)*
2. *= agree (favorable)*
3. *= undecided*
4. *= disagree (unfavorable)*
5. *= strongly disagree (unfavorable).*

A weighted mean is measured by: $\mu_{\text{Likert}} = \sum_{i=1}^{n} i * P_i, \quad i = 1,2,3,4,5$

where, μ_{Likert} is the weighted mean, i is the rate scale, and P_i is the proportion of observations of the $i-th$ scale. The results are reported in Tables 4, 5 and 6. In the tables, μ_1 represents the weighted mean for the Likert scale of OCPC; and μ_2 represents averages of consumers who had never purchased OCP. The relative rankings of the weighted means are plotted in Figure 4, 5 and 6.

(1) The consumer conceptions of OCP

The consumer conceptions of OCP are measured by positive items of (1) environmental friendly (2) health, (3) comfort, (4) protect farmers, (5) in vogue, (6) representing social rank, (7) satisfying curiosity, and by negative items of (8) not related to environment, (9) rash and reckless. The analysis results of the consumer concepts toward OCP are provided in Table 4 and Figure 4. The χ^2 test revealed that the concepts of the OCPC and non-OCPC toward OCP are significantly different, even though both generally agree with the positive items more than the negative items with the same ranking order among the 9 items of concepts toward OCP. Both OCPC and non-OCPC agree with the idea that OCP is environmentally friendly, healthy and comfortable, while the OCPC have higher agreement. Most respondents do not agree that OCP consumption is rash and reckless. The results indicate that further increasing the positive concepts of OCP can further increase the OCP purchase propensity.

(2) Consumer considerations when purchasing

Important considerations when consumers purchase commodities are measured by items of (1) reliability of retail stores, (2) reliability of certification, (3) price, (4) services after purchase, (5) commercial advertisement, (6) convenience of purchasing, (7) styles, (8) places of production, (9) fame of the brand, (10) professional recommendation, and (11) delicate packaging. Analysis results are provided in Table 5 and Figure 5. According to the rank of weighted means, the OCPC take the reliability of the retail store and the reliability of certification seriously and pay less attention to commercial advertisements and delicate packaging. The non-OCPC emphasize places of production, reliability of certification, reliability of the retail stores, services after purchase, and then price, but pay less attention to commercial advertisement. The χ^2 test revealed that the importance of the considerations of the OCPC and non-OCPC are insignificantly different in three items: prices, styles, places of production. The concerns of OCPC and non-OCPC when purchasing commodities are quite different, as indicated by the significance evidence of the χ^2 test in all the other items, including reliability of retail stores, reliability of certification, services after purchase, commercial advertisement, convenience of purchase, fame of the brand, professional recommendation, delicate packaging.

(3) Consumer clothing habits

The consumer clothing habits are measured by the items of (1) made from natural textile, (2) emphasize comfort, (3) made from cotton (4) in vogue, (5) emphasize individual preference, (6) made from synthetic textile, and (7) do not care about the textile. The analysis results of the consumer clothing habits are provided in Table 6 and Figure 6. According to the relative ranking of the asking items, both OCPC and non-OCPC take the clothing textile and comfort seriously. The clothing of OCPC tends to be made from natural textiles and to be made from cotton. The non-OCPC clothing habits tend to be in vogue, and to emphasize individual preference. Both the OCPC and non-OCPC do not wear clothes made from synthetic textile and not they do care about the clothing textiles. Additionally, the χ^2 test reveals that there is no decision difference between the OCPC and non-OCPC in terms of clothing comfort.

(Table 4 OCPC purchase decision and consumer concepts toward OCP)

(Table 5 OCP purchase decision and the considerations when consumers purchase)

(Table 6 OCP purchase decision and consumer clothing habits)

(Figure 4 relative rankings of the weighted means for the consumer conceptions of OCP)

(Figure 5 Relative rankings of the weighted means for the consumer OCP considerations when purchasing)

(Figure 6 Relative rankings of the weighted means of consumer clothing habits)

Question 5: What are the main channels of OF information, main sites of OF purchase and years of OF consumption? Are there a difference between OCPC and non-OCPC?

The analysis results of OF information channels and consumption years are presented in Table 7. The main sources of information for OCPC are relatives, friends, stores, newspapers and magazines, while the main sources of information for non-OCPC are newspapers, magazines, TV and organic exhibition. Most channels of information are suggested to be different between the OCPC and non-OCPC by the χ^2 test. A common ranking order of purchase channels for OCPC and non-OCPC is organic stores, physical stores and organic exhibitions. Most channels of purchase are suggested to be different between the OCPC and non-OCPC by the χ^2 test.

Consumers purchase OCP after several years of OF purchase experience, and most OCPC have more than three years of OF consumption experience. The purchase frequency of OCP is low among new purchasers of OF, and with longer years of OF consumption, there is higher propensity for OCP purchase. This is evidenced by both the distribution of the observation and the χ^2 test. Years of OF consumption differ between OCPC and non-OCPC.

(Table 7 Purchasing decision under different channels of information, different channels of purchase and years of purchase)

Question 6: Does OCPC purchasing vary among consumers of different demographic characteristics?

The demographic variables included in this study are (1) gender, (2) age, (3) education, (4) religion, (5) participation in environmental protection groups, (6) having previously donated for environmental protection, (7) marital status, (8) number of children, (9) monthly household income, and (10) occupation.

The analysis results are reported in Table 8. Females are more apt to purchase

OCP than males as indicated by the purchase numbers for males and females and the significant χ^2 test in Table 8. OCP are often purchased by consumers over 30 years old. The age-group χ^2 test revealed that OCP consumption behavior is different in younger and elder groups in that younger people are less apt to buy OCP. The OCP purchase behavior does not differ among consumers with different education levels. Since OCP consumption is advocated by some religious and environmental groups, the frequency of OCP consumption and the χ^2 tests in Table 8 suggest that consumers who are Buddhists, have been a member of environmental protection groups and have donated for environmental protection are more likely to consume OCP. These results also suggest that environmental concerns and participations are highly related to the OCP purchase.

A married person is more likely to purchase OCP, than an unmarried one, and the purchase propensity is higher if the number of children in the household is low. A non-linear relationship between the OCP purchase and household income was found. OCP purchases are not significantly different in low income groups (monthly income less than 35 thousand NTD) and high income groups (monthly income over 115 thousand NTD). They differ only in the income of the middle groups at 0.01 significant levels. In addition, consumers whose occupation is in the public and business sectors are more likely to purchase OCP than those in other sectors.

Question 7: Does the OCP and OF purchase behavior differ among OCPC?

According to the sample information in Table 8 for OCP consumers in this study, the OCPC have different purchase behavior when they purchase OF and OCP. The behaviors differ in channels of information, channels of purchase, and years of purchase. There also is a negative relationship between the likeliness of OCP purchase and time length of OF purchase.

(Table 8 Purchase decision and demographic variables)

(Table 9 Purchase behavior of OCPC toward OF and OCP)

V Conclusions

Organic cotton products offer a new opportunity for global environmental protection. To consume organic cotton can clearly reduce the use of chemicals worldwide, and thus directly contribute to environmental protection and human health. However, increased production of organic cotton products appears to be limited by its small market share, as compared to the global market for conventional cotton products. To expand the demand for the organic cotton products by expanding consumer support through consumer analysis can effectively increase its market share and levels of production.

In Taiwan, organic cotton initiatives have been advocated by Buddhism and environmental groups, although organic cotton products are still only small market niches for producers. They are in the early stage of the life cycle of a product. Since Taiwan's humid weather is not suitable for cotton cultivation, all of the raw materials for Taiwan's cotton textile industry are imported. The organic cotton product industry in Taiwan can be expanded through Taiwan's already developed textile industry, by reducing its reliance on chemicals. Taipei is Taiwan's initiation center for organic cotton products and organic food consumers are the potential consumers for organic cotton products due to their higher levels of understanding and acceptance. This study investigated the purchase behavior of Taipei's organic food consumers for organic cotton products. Several conclusions have been drawn from the study.

Knowledge concerning organic cotton products is the primary determining factor for purchase of organic cotton products, and a failure to purchase organic cotton products is mainly due to incomplete understanding. Currently, organic cotton products in Taiwan are in early stages of product development. Very few people have heard about organic cotton products, and even fewer have purchased them. In addition, since cotton products are usually for external use, rather than intake, the health connection to the consumers are not as direct and immediate as the chemical contaminations of foods. The automatic feedback mechanism is less sensitive.

Therefore, the voluntary interest and purchasing often emerge after the consumers have better understanding. This understanding of OCP can be increased by frequent massage provides through media and public environmental education. Moreover, this study consistently indicates that consumers with positive views of organic cotton products are much more likely to purchase them. Furthermore, consumers who have participated in environmental groups and/ or donated for environmental protections are likely to purchase organic cotton products. Therefore, providing the public environmental education and relevant information through a variety of media is important to raise the level of understandings and thereby increase the consumption, market scale and the health of the environment. The purchase of organic apparel is highly related to the knowledge and environmental attitudes of the consumers. A similar suggestion has been made regarding organic cotton apparel consumption in Hawaii, USA (Lin, 2009).

Organic food consumers usually consider the organic food certifications and places of productions when they purchase organic food. Compared to organic foods, due to the small market scale and international chains of production for cotton textiles, the certification of organic cotton products in Taiwan relies mainly on the international certifications that are provided by importers without reliable local certifications. Therefore, local consumers can only rely on the credibility of the retailers, especially when they are not familiar with the complex international certifications and places of production. Additionally, consumers tend to purchase organic cotton products in physical organic shops rather than web-shops due to the reliability. The purchase decisions for organic cotton products are often made under the recommendations of relatives and friends of the consumers based on personal trust, rather than through commercial advertisements and media. Clearly, the reliability of organic cotton certifications and credibility of the retail store are central concerns for the consumers who are already familiar with the advantages of organic cotton products.

Additionally, product price and consumer income are not determining factors for the purchase of organic cotton products. In Taiwan, the development of local organic cotton product manufacture has made their prices lower than the prices of imported finished organic cotton products. That is, consistent with the observation of Nimon and Beghin (1999) that prices of American organic apparel are not significantly higher than those of traditional cotton products. Moreover, purchase of organic cotton products does not increase with income, i.e. consumption is not linearly income-determined, and there is a non-linear relationship between income and the willingness to purchase of organic cotton products. According to gender analysis, the proportion of women purchasing organic cotton products is higher than that of men.

In conclusion, the key point for consumer promotion is providing increased public information on the advantages of organic cotton products. Suggestions go to that the organic cotton producers should earn the trusts of the rational consumers, especially female consumers, by reliable provision of trustworthy organic cotton products, rather than commercial advertisements. Increased in consumer satisfaction can increase the possibility of re-purchase and purchase by relatives and friends through internet-externality. In addition, local organizations should be established to approve both the domestic and imported organic cotton products. There is a deep demand for reliable local organizations to deal with certification of organic cotton products. To increase in credibility of certifications is to enlarge the levels of consumption and the production. On the basis of its thriving textile industries, Taiwan has good potential to develop the manufacture of organic cotton products after fulfilling the further expansion in the consumption of organic cotton products.

This research were based on information from study participants in Taipei, Taiwan, and further research can compare characteristics of potential organic cotton consumers in different regions of the world.

References

Hsieh, Y. L. 2007, A Consumer Analysis of Organic Cotton Products in Taiwan, Master's Thesis of Department of Economics, Chinese Culture University, Taiwan.

E.J.F. 2007, The Deadly Chemicals in Cotton. Environmental Justice Foundation in Collaboration with Pesticide Action Network UK: London, UK. ISBN No. 1-904523-10-2.

Engel, J. F., R. D. Blackwell, and P. W. Miniard, 1995, Consumer Behavior, 8th ed., Dryden Press, Orlando, USA.

Eyhorn, F., S. G. Ratter, and M. Ramakrishnan, 2005, Organic Cotton Crop Guide: A Manual for Practitioners in the Tropics. Research Institute for Organic Agriculture (FiBL), Ackerstrasse, Switzerland.

Ferrigno, S., S. G. Ratter, P. Ton, D. S. Vodouhê, S. Williamson and J. Wilson, 2005, Organic Cotton: A new Development Path for African Smallholders, International Institute for Environment and Development, London.

Forsythe, J. L. 1980, "World Cotton Technology since World War II," Agricultural History, 54 (1): 208-222.

Jodlbauer, H. 2008, "Customer Driven Production Planning," International Journal of Production Economics, 111: 793-801.

Lin, S. H. 2009, "Exploratory Evaluation of Potential and Current Consumers of Organic Cotton in Hawaii," Asia Pacific Journal of Marketing and Logistics, 21(4): 489 - 506.

Lucas, S. C. 2007, "An Organic Matter," Cotton International Magazine, 5(5): 26.

Menon, M. 2003, "Green Gold: Commercial Organic Cotton," Appropriate Technology, 30(3): 8.

Myers, D. and S. Stolton, (eds) 1999, Organic cotton: From Field to Final Products, Intermediate Technology Publications, http://www.pan-germany.org/.

Nimon, W. and J. Beghin, 1999, "Are Eco-Labels Valuable? Evidence from the Apparel Industry," American Journal of Agricultural Economics, 81(4): 801-811.

Organic Exchange Organization (2010) http://www.organicexchange.org/press.php

Ridgway, R. L., E. P. Lloyd, and W. H. Cross, 1983, Cotton Insect Management with Special Reference to the Boll Weevil. USDA, Washington DC, USA.

Speer, J. K. 2005, "Organic Cotton: Where, Why and How," Apparel Magazine, 46: 15-43.

Tean, K. 2007, "Industry Navigates Organic Cotton Boom," Women's Wear Daily, 10: 6.

Wilson, B. 2004, "Organic Cotton Takes Root," Women's Wear Daily, 187: 10.

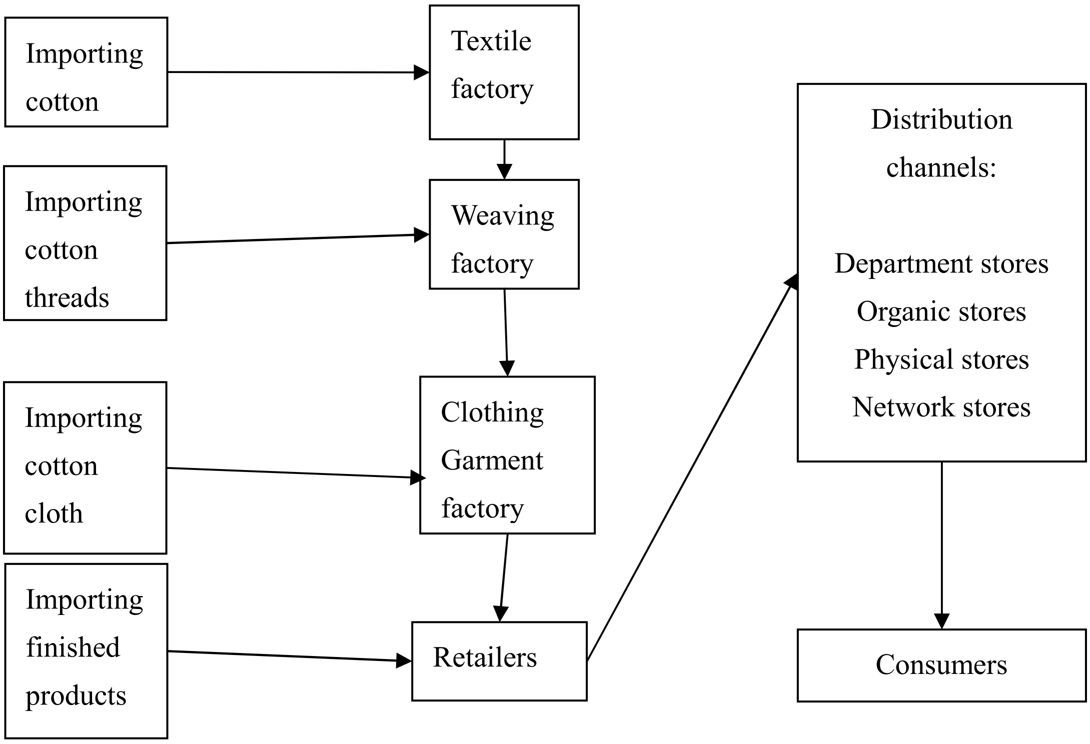


Figure 1 Production chains of organic cotton products in Taiwan
Source: Organized from the information of focus group interviews of this study

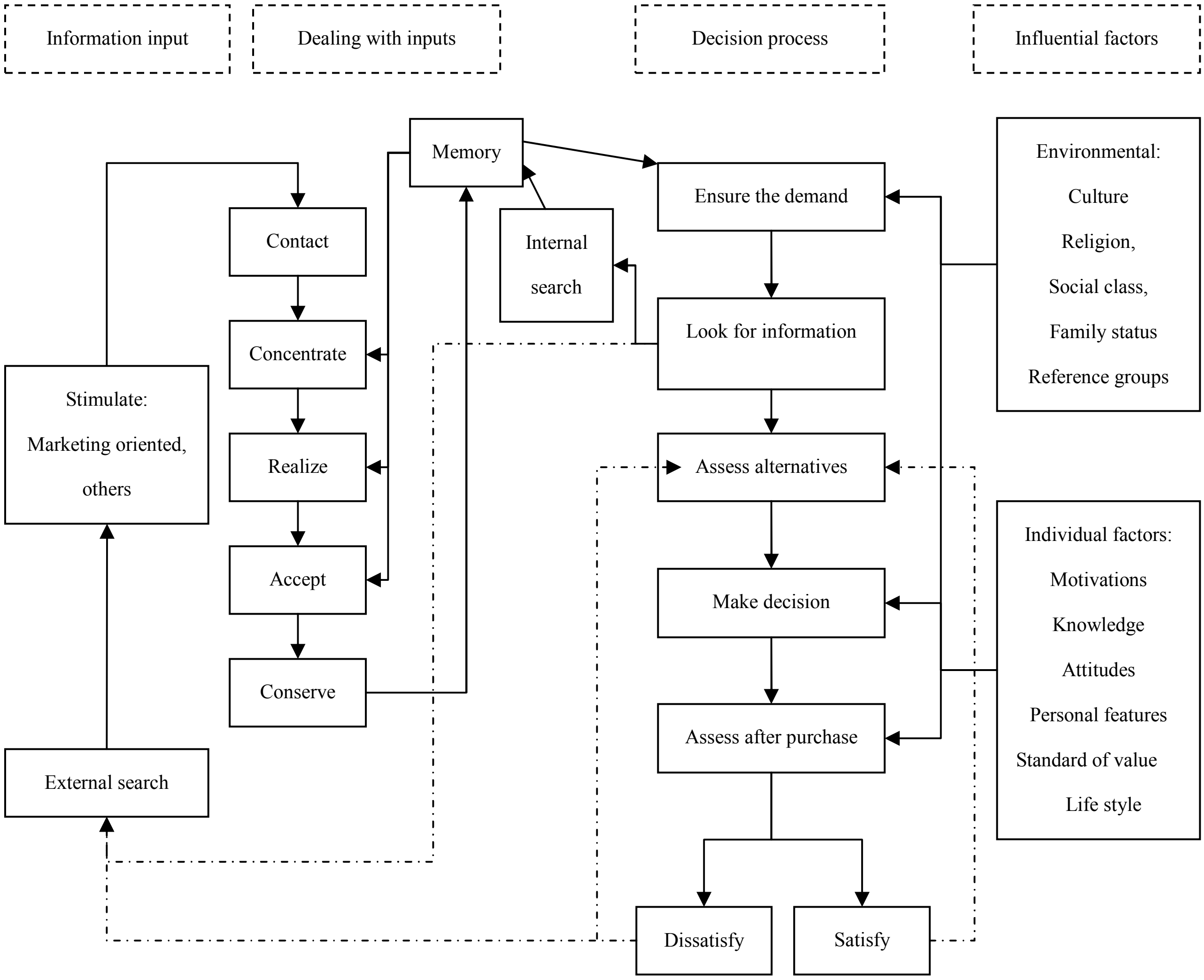


Figure 2 Structure of EBM consumption behavior

Source: Amended from Engel, Blackwell and Miniard, 1995, p.237

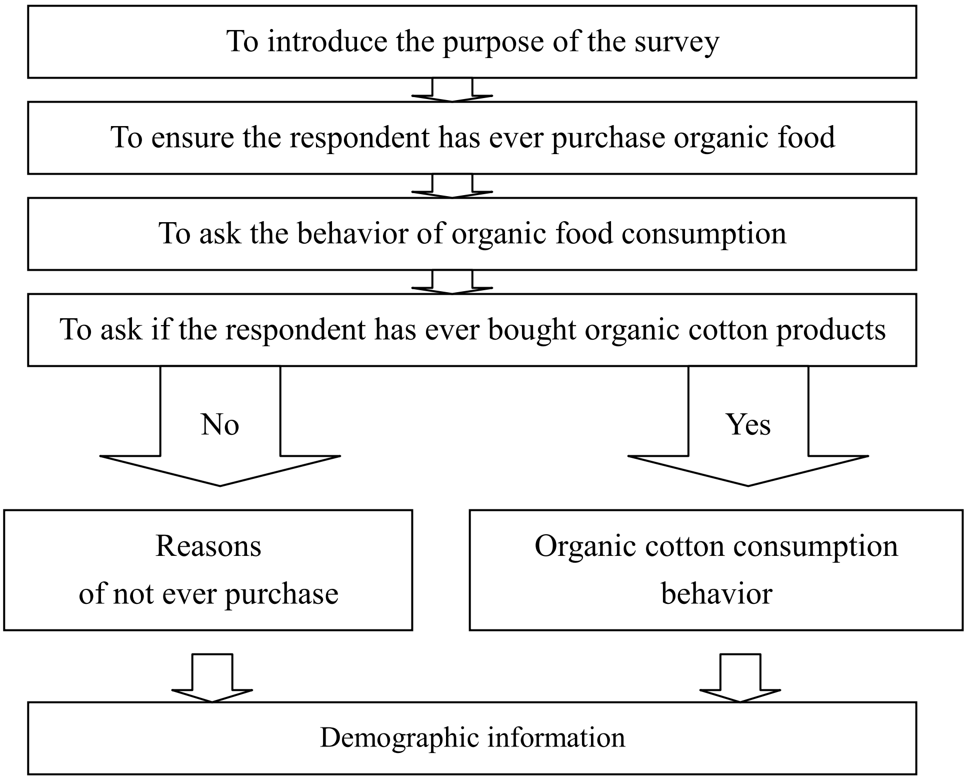


Figure 3 Structure of interview questionnaires

Note: “Yes” and “No” represents have and not have previously purchased organic cotton products

Table 1 OCP purchase decisions and knowledge of OCP

Knowledge of OCP	Number of OCPC	Number of non-OCPC	P-value of χ^2 test
Understand OCP very well	75	0	-
Understand OCP well	14	5	<0.001**
Had heard of OCP but did not understand very well	16	117	<0.001**
Had never heard of OCP	0	167	-
Total	105	289	<0.001**

Note: “-“ represents not applicable for testing with 0 observation in some categories.

Table 2 Distribution of OCP consumption in Taiwan

	Number of respondent	Percentage
Yearly purchase frequency (time)		
1	14	13.33%
2 – 3	47	44.76%
4 – 5	31	29.52%
6 and over	13	12.37%
Average expenditure per purchase (NTD)		
0 - 1,000	16	15.24%
1,001 - 3,000	37	35.24%
3,001 - 5,000	26	24.76%
5,001 - 7,000	11	10.48%
7,001 - 10,000	9	8.57%
10,001 and over	6	5.71%
Most purchased items +		
Towels	74	21.77%
Socks	68	20.00%
Underwears	66	19.41%
Shirts	45	13.24%
Napkin	38	11.18%
Children's clothes	13	3.82%
Beddings	23	6.76%
Dolls	2	0.59%
Others	11	3.24%
Need to increase Styles +		
Underwears	45	18.75%
Towels	42	17.50%
Beddings	38	15.83%
Shirts	27	11.25%
Children's clothes	21	8.75%
Socks	19	7.92%
Napkin	13	5.42%
Dolls	12	5.00%
Others	23	9.58%

Note: The symbol $^{+}$ represents multi-choice question.

Table 3 Frequency of reasons for failing to purchase OCP among Taiwan's OFC

Reasons of not purchase[+]	Respondent number
Never heard	147
Not understand	142
Lack choices with few styles	43
Price is too expensive to buy	25
Individual power is too small to change the environment	5
Not realistic	4
Dislike by family members	0
Others	15
Total	381

Note: The symbol + represents multi-choice question, in which the total number is higher than the sample size.

Table 4 OCPC purchase decision and consumer conception of OCP

Conception	μ_{Likert}		P-value of χ^2 test
	μ_1	μ_2	
Environmental friendly	4.70	4.17	<0.001**
Health	4.67	4.12	<0.001**
Comfort	4.54	3.97	<0.001**
Protect farmers	3.85	4.04	<0.001**
In vogue	3.83	3.49	<0.001**
Representing social rank	2.72	3.01	0.004**
Satisfying curiosity	2.64	3.31	<0.001**
Not related to environment	1.60	2.29	<0.001**
Rash and reckless	1.59	2.41	<0.001**

Note: ** represents significant at 1%. μ_{Likert} is average of Likert scales. μ_1 represents weighted mean of Likert scales of respondents that has ever purchased OCP; and μ_2 represents averages of those has not ever purchased.

Table 5 OCP purchase decision and the considerations when purchasing

The considerations	μ_{Likert}		P-value of χ^2 test
	μ_1	μ_2	
Reliability of the retail stores	4.67	4.36	0.001**
Certification	4.61	4.39	0.025*
Price	3.98	4.10	0.361
Services after purchase	3.88	4.24	0.001**
Commercial advertisement	2.82	3.33	<0.001**
Convenience of purchasing	3.63	3.93	0.001**
Styles	3.80	3.82	0.754
Places of production (cultivation and manufacture)	3.71	4.46	0.368
Fame of the brand	3.57	3.74	0.017*
Professional recommendation	3.50	3.51	0.001**
Delicate packaging	3.19	3.66	<0.001**

Note: The same as Table 4.

Table 6 OCP purchase decision and consumer clothing habits

Clothing habits	μ_{Likert}		P-value of χ^2 test
	μ_1	μ_2	
Made from natural textile	4.69	3.34	<0.001**
Emphasize comfort	4.19	4.18	0.603
Made from cotton	4.02	3.71	0.001**
In vogue	2.86	4.95	<0.001**
Emphasize individual preference	3.82	4.03	0.044*
Made from synthetic textile	2.38	2.28	<0.001**
Do not care about the textile	2.01	2.71	0.603

Note: The same as Table 4.

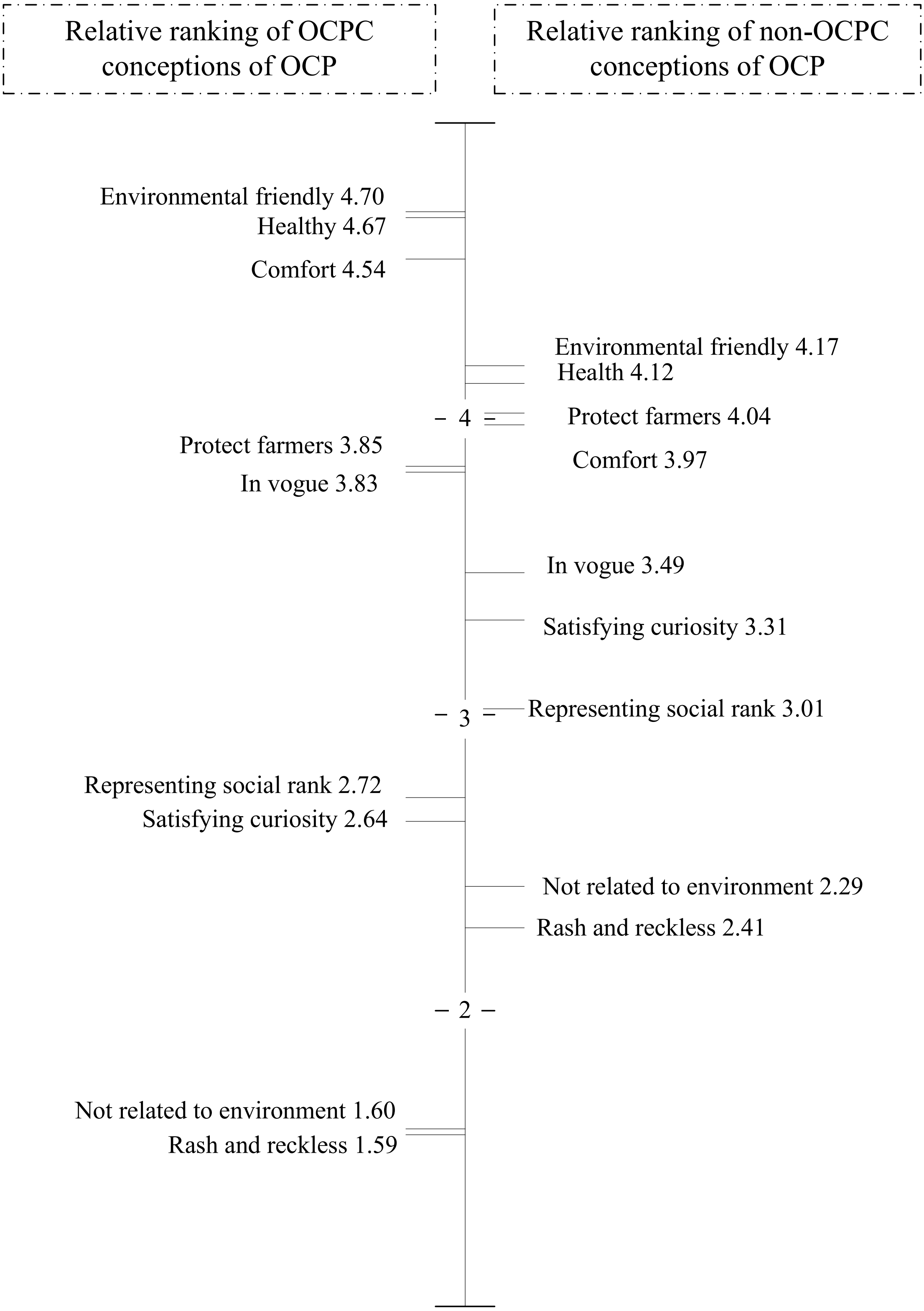


Figure 4 Relative rankings of the weighted means for consumer conceptions of OCP

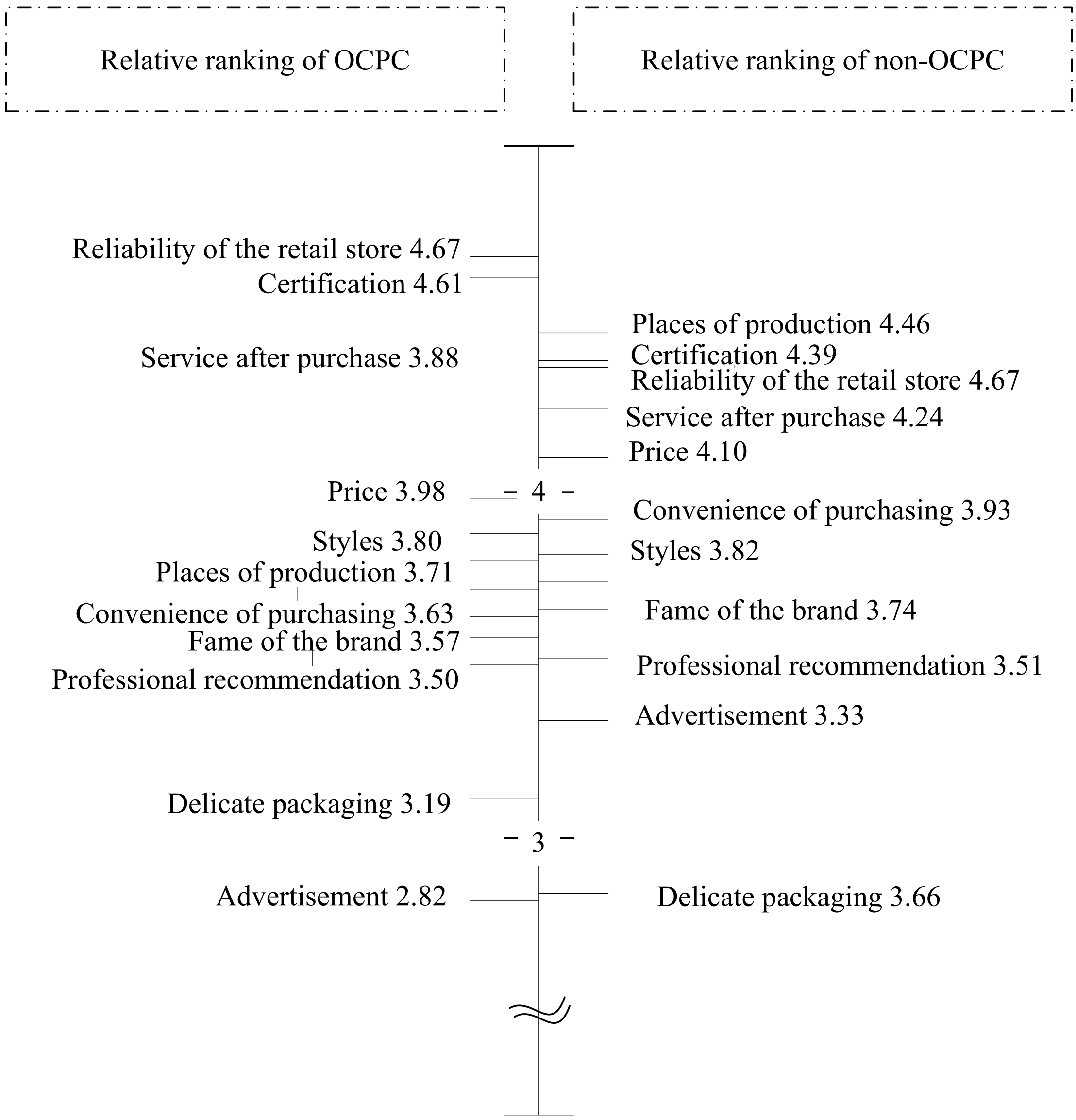


Figure 5 Relative rankings of the weighted means for the consumer considerations when purchasing

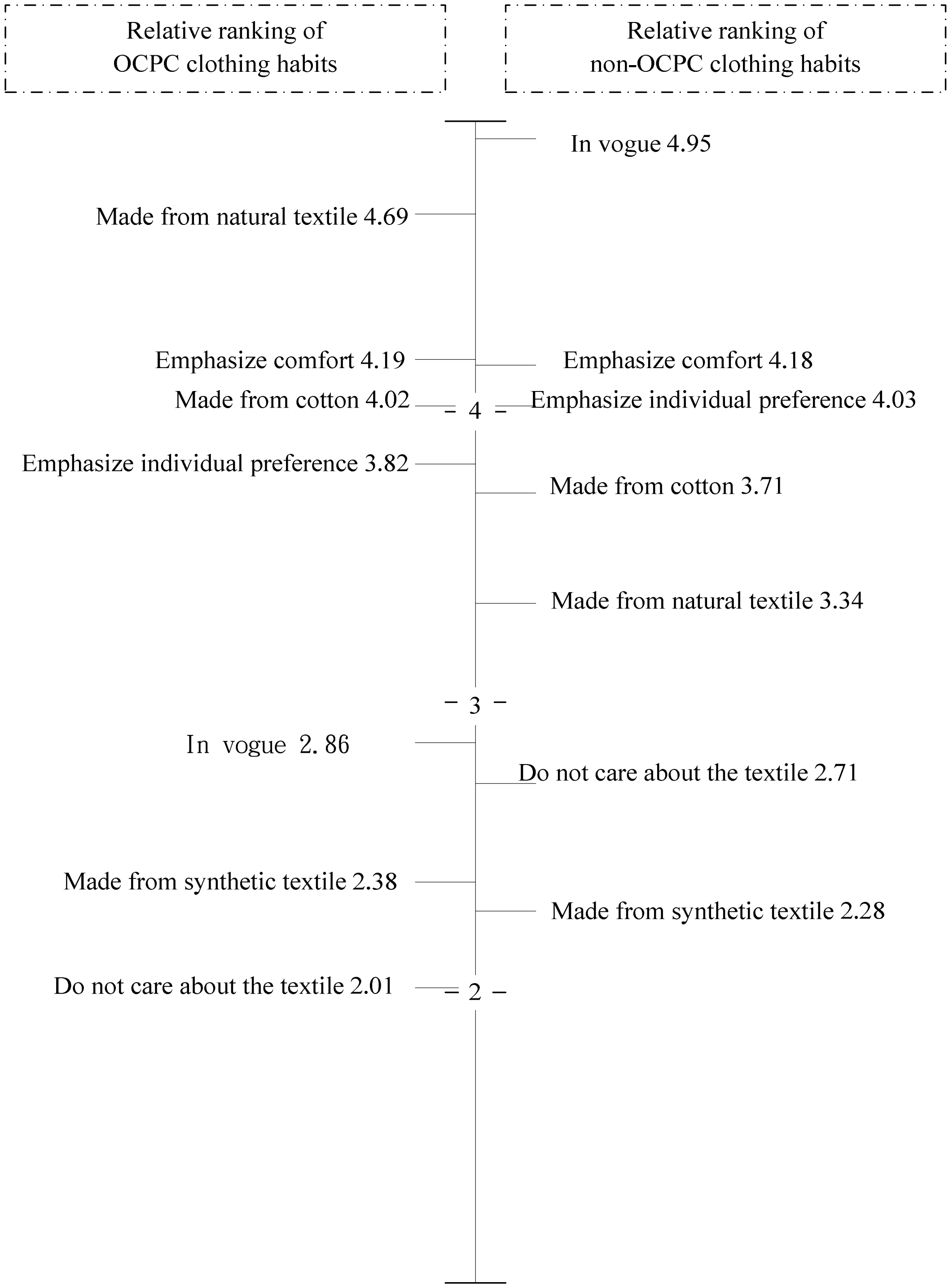


Figure 6 Relative rankings of the weighted means of consumer clothing habits

Table 7 Purchasing decision under different channels of information, different channels of purchase and years of purchase

	number of OCPC	number of non-OCPC	P-value of χ^2 test
Channels of information+			
Relatives and friends	52	70	<0.001**
Stores	37	71	0.036*
Newspapers and magazines	30	151	<0.001**
Organic exhibitions	23	111	0.002**
TV	21	128	<0.001**
Professional books and journals	21	48	0.434
Internet	10	83	<0.001**
Broadcast	7	36	0.103
Medicine	5	18	0.583
Others	32	16	<0.001**
Channels of purchase+			
Organic stores	85	171	<0.001**
Physical stores	26	113	0.006**
Exhibition	21	101	0.004**
Web stores	3	65	<0.001**
Others	12	32	0.327
Years of OF consumption	105	289	<0.001**
Less than 6 months	7	94	<0.001**
6 months to less than 1 year	9	40	0.161
1 year to less than 2 years	19	48	0.728
2 year to less than 3 years	11	34	0.655
3 years and above	59	73	<0.001**

Note: * and ** represent significant at 5% and 1%, respectively. The symbol + represents the multi-choice question and the total number in the multiple question is higher than the sample size.

Table 8 Purchase decision and demographic variables

	number of OCPC	number of non-OCPC	P-value of χ^2 test
Gender	105	289	0.041*
Female	83	198	
Male	22	91	
Age	105	289	0.000**
Under 17 year old	0	9	-
18-25 year old	1	52	<0.001**
26-30 year old	7	51	0.007**
31-40 year old	31	66	0.173
41-50 year old	28	61	0.243
Over 51 year old	38	50	<0.001**
Education	105	289	0.189
Elementary	2	1	0.116
Junior high school	3	13	0.466
Senior high school	11	52	0.072
Professional college	22	48	0.319
University	56	138	0.327
Master	11	33	0.793
Ph. D.	0	4	-
Religion$^+$	107	403	
No religion	17	94	0.001**
Buddhism	86	121	<0.001**
Taoism	4	29	0.049*
Other	0	52	-
Member of environmental protection group	105	289	<0.001**
Yes	56	56	
No	49	233	(continuous)

Note: - represent not applicable. * and ** represent significant at 5% and 1%. + represents multi-choice questions. The total number may higher than the sample size.

Table 8 (continuous)

	number of OCPC	number of non-OCPC	P-value of χ^2 test
Ever donate for environmental protection	105	289	<0.001**
Yes	66	106	
No	39	183	
Marriage	105	289	0.008**
Married	65	135	
Single	40	154	
Number of children	105	289	0.003**
0	41	169	0.001**
1	18	27	0.031*
2	36	72	0.065
3 and over	10	21	0.462
Monthly household income (NTD)	105	289	0.002**
0 - 15,000	6	29	0.183
15,001 - 35,000	16	60	0.219
35,001 - 55,000	20	84	0.046*
55,001 - 75,000	12	37	0.715
75,001 - 95,000	17	26	0.043*
95,001 - 115,000	21	25	0.002**
115,001 and over	13	28	0.439
Occupation^{+}			
Public sector	40	34	<0.001**
Service sector	15	76	0.012*
Housewife	11	27	0.736
Business	10	62	0.007**
Retired	8	12	0.166
Freelancer	5	13	0.973
Manufacture	2	14	0.191
Agriculture	0	1	-
Student	0	34	-
Others	14	18	0.001**

Table 9 Purchase behavior of OCPC for OF and OCP

	number of OF	number of OCP	P-value of χ^2 test
Channel of information+			
Relatives and friends	52	48	<0.001**
Stores	37	45	<0.001**
Newspaper and magazine	30	26	<0.001**
Exhibition	23	16	<0.001**
Professional books and journals	21	16	<0.001**
TV	21	12	<0.001**
Broadcast	7	2	0.013*
Network	6	10	<0.001**
Others	37	39	<0.001**
Channels of consumption+			
Organic store	85	88	<0.001**
Physical store	26	26	<0.001**
Exhibition	21	9	<0.001**
Web store	3	5	<0.001**
Others	11	10	<0.001**
Years of OF consumption			
Less than 6 months	7	12	<0.001**
6 months to less than 1 year	9	25	0.002**
1 year to less than 2 years	19	19	<0.001**
2 year to less than 3 years	11	22	<0.001**
3 years and above	59	27	<0.001**

Note: * and ** represent significant at 5% and 1%. + represents multi-choice question.

Cost Reduction and Capacity Output of Fishery Management in Japan

Michiyuki Yagi[*] and Shunsuke Managi[†]

Abstract

Japan's fishery harvest peaked in the late 1980s. Providing individually specific catch shares of the Total Allowable Catch (TAC) to each fisherman is the key to avoid the race for fish. Thus, in moving the idea into practice with the actual implementation of catch shares, it is crucial to estimate the potential cost reduction in the industry. We find that the maximum level of production the fixed inputs in Japan are capable of supporting (i.e., capacity output) could be three times higher. Conversely, current overall fixed inputs could be reduced to one-tenth. Getting rid of these inefficient fishers would help lead to sustainable fishery management. These significant potential results are important for policy purposes. For example, about 300 billion yen (about 3 billion dollars) can be saved by allocating individually specific catch shares to each fisherman.

Keywords: Capacity Output; Capacity Utilization; Individual Quotas; Production Frontier; Japan.

JEL Classification: Q22; Q18; L70.

[*] Doctor's Course 1st grade, Graduate School of Environmental Studies, Tohoku University
[†] Graduate School of Environmental Studies, Tohoku University

1. Introduction

The existence of overcapacity in the fisheries is largely responsible for overfishing, for the dissipation of food production potential and for significant economic waste (Food and Agriculture Organization (FAO), 2008a). Compounding the overcapacity problem would depend in large part on the race to fish due to “tragedy of the commons.” Literature in resource economics has focused on the sustainable use of renewable resources since the mid-1950s (i.e., Gordon, 1954). In many countries, the fishery is known as a classic case of mismanagement of common-pool resource. For example, the total volume of fish caught from 1979 through 2005 for developed countries has steadily declined (FAO, 2008b).

In many parts of the world, fisheries are currently both biologically and economically overexploited (Pasco et al., 2004). This could be true of Japanese fishing industry. Japanese fishery catches have been decreasing over the last two decades. Catches in 2006, for example, totaled about 55 thousand metric tons (Fig. 1). This is only 44 % of 1987 production (FAO, 2008b). The number of vessels and fishermen have also been diminishing, and are 308,335 and 411,040 in 1987, and 210,246 and 212,470 in 2006, respectively (Annual Statistics of Fishery and Fish Culture, 2006). In contrast, labor productivity (i.e., fishery production value per worker, where fishery production refers to the output of fish by humans from capture fisheries) and capital productivity (i.e., value per fishing vessel) are relatively stable for total catch amount excluding Sardine. During the past 30 years, there has been a maximum of about 20% difference or fluctuation.

It is possible to build up one hypothesis that there is a negative spiral of overcapacity due to "race for fish" in Japanese fishing industry. When there was a great deal of fish stocks until the early 1980's, fishermen would have invested in fishing vessels since they would think they could earn profits from the investment. Once the fish stock decreased in the late 1980s, their profits would begin to be diminishing. In response to this, an additional increase in the fishing effort would occur since they might attempt to recover economic losses of the investment. Then the fish stocks would have still been decreasing due to further fishing pressure, and the fishermen might have to increase additional efforts or to exit the industry. As a result, the Japanese fishing industry seems to have been shrinking for decades. In fact, the number of the coastal fishing boats and the production amount of coastal fishery are decreasing continuously (MAFF, 2005a).

In general the existence of overcapitalization is often attributed to the lack of property rights in fisheries (Pasco et al., 2004). Various types of property rights with different characteristics have been used to address common-pool resource externalities and include the community management of fisheries (Grafton et al., 2000). Japan’s coastal fisheries, in particular, appear to satisfy the conditions for enduring community rights (Asche et al., 2008). This is because the most coastal fisheries of Japan illustrate how communities can effectively manage resources in a sustainable way and provide substantial benefits to the fishers through a mix of community and private rights (Ruddle, 1989; Yamamoto, 1995).

Meanwhile, transferability of individual quotas provides incentives for efficient harvesters to acquire quota from less efficient harvesters leading to a reduction in harvesting capacity (Asche et al. 2008). This will improve overall harvesting efficiency in the fishery and generate rent. In principle, a well-designed individual transferable quota (ITQ) system - one of the catch shares systems - will allow resource rents to be generated through a reduction in excess capacity arising from quota trading, although there is also evidence that this is a long-run process that may take substantial time (Grafton et al., 2000; Asche et al., 2008).

Specifically, due to the lack of property rights, the close-knit communities of fisheries in Japanese would be mostly unwilling to admit that it is necessary to improve management efficiency by productive fishermen or fishing entities. Profitable communities would be reluctant to receive outside productive fishermen because community members would not want to decrease each present profit and because young persons living in the communities would take the job as successors primarily. On the other hand, unprofitable fishery communities would also like not to induct outside fishermen or not to restructure because current low profits would be subdivided again. Even if the unprofitable communities seem to recruit outside fishermen, there could be indeed only jobs with low productivity that even the young living there would not want to do in the most cases.

However, all ITQ programs share the problem of initial quota allocations to fishers (Grafton et al., 1996). In many countries implementation of the individual property rights system has been difficult because of political, ideological, and regulatory issues. For example, there are strong obstacles for the implementation in Japan of incentive based policies such as ITQs because no previous studies have estimated the potential of alternative policies and there is concern about any uncertain outcome (Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), 2008).

In the literature of theoretical and empirical fishery economics, the recommended policy prescription for fisheries management is the catch shares system. Catch shares grant each fisherman the right to harvest a given percentage of the total allowable. Each fisherman has an incentive to manage it well because the value of these shares increases with the productivity of the fishery product. For example, Costello et al. (2008) show that the fisheries management strategy of catch shares can reverse a collapse in fisheries. They find that the proportion of fisheries managed by ITQs that had gone into bankruptcy by 2003, was half that of the non-ITQ fisheries. That is, the alternative policy is better for both fish and fishermen.

Characters of fisheries policies in place in Japan are Total Allowable Catch (TAC) and Total Allowable Effort (TAE) systems, national and prefectural government licensing systems and a lot of government financial transfers (GFTs). TAC is a catch limit set for a particular fishery, generally for a year or a fishing season and is usually expressed in tonnages of live-weight equivalent, but is sometimes set in terms of numbers of fish (OECD, 1998). TAE sets an upper limit on the number of fishing days and the number of operating vessels in a specific area within the Exclusive Economic Zone (EEZ).

Given the declining fish catches, the Japan Fisheries Agency enacted the “Basic Law on Fisheries Policy” in June 2001. The law is a new guideline for fishery policy replacing the “Coastal Fishery and Others Promotion Law” of 1963, whose primary aim was to improve fishery productivity. The Basic Law has two key concepts: 1) securing a stable supply of fishery products; and 2) the sound development of the fisheries industry to promote the appropriate conservation and management of marine living resources.

In 1995, the Japan Fisheries Agency started to reduce the number of fishing vessels and restrictions on fishing area and/or period for some fisheries in order to ensure the sustainable use of fishery resources. The TAC system has also been implemented. The principal laws are “The Fisheries Law”, the “Living Aquatic Resources Protection Law” and the “Law Concerning Conservation and Management of Marine Living Resources.” These principal laws were also amended in keeping with the concept of the “Basic Law on Fisheries Policy.” The central and prefectural governments regulate fishing efforts in terms of fishing methods. The TAC system assigns TAC allocations to each fishery separately, not to individual fishermen. While seven fish species are subject to the TAC system, covering about 30% of total fishing in Japan in 2000, TAE was established as a system to manage total allowable effort with the amendment of the “Law Concerning Conservation and Management of Marine Living Resources.” The TAE includes curtailing the number of boats, suspension of operations, and improvement of fishing gear among others. However, these regulations are not effective and the catch has been decreasing continuously. Essentially, the regulations are too loose to control the actual activities of fishermen.

Meanwhile, the amount of GFTs related to fisheries in Japan (JPY 271 billion in 2003), which tends to decline slightly over years, is much larger than most OECD countries (OECD, 2006).

The largest amount of the GFTs related to fisheries in Japan is allocated to the construction of coastal infrastructure (JPY 203 billion in 2003), i.e. fishing ports, other coastal public facilities, etc, and this GFT seems to be justified since this does not constitute payments to fishing industries.

The other financial support provided by Japan to the fishing industry are direct payments for fishery restructuring (JPY 2 billion in 2003), interest subsidies (JPY 3 billion in 2003), which is designed to assist structural adjustment of coastal fisheries under certain conditions and general services expenditure (JPY 62 billion in 2003; OECD, 2006). The amounts of GFTs to direct payments for restructuring and interest subsidies are much lower than those to the others. These subsidies apparently are justified since they do not contribute to the increase of fishing capacity.

However, how do fisheries policy-makers in Japan recognize see the fishing industry developing in the future at all? Alternatively, do they at least know how much fishing capacity there is or how efficiency most of the fisheries entities are? They seem not to demonstrate their recognition of the fishing capacity, and it will be impossible to manage the fishing industry without the information. The ocean fisheries in Japan are freely accessible (or have open access) because their TAC caps have been too loose to restrict the activity of fishermen. In most cases the caps of TAC were more than those of Allowable Biological Catch (ABC), which is a level of a stock that accounts for the scientific uncertainty in the estimate of overfishing limit, until 2009 in Japan. In addition, the financial supports seem to try to merely maintain the capacity in stable condition, and appear to abandon the administration of the fishery capacity.

Thus, the core question in our study is, “is there significant potential profitability in Japan’s fishery industry assuming that we are able to set the optimal individually specific catch shares?” The catch share is used and assumed as the most realizable policy we suppose. Given the importance of fishery management and production in Japan, this study analyzes the quantitative potential of optimal input/output allocations by assigning optimal Individual Quotas (IQs). Our results show the ideal case of the potential catch shares system in one regard. The catch shares system divides the total permitted catch in a fishery into shares. That is, under the systems, yearly limits, or quotas, are set on a fishery.[‡] This is because, given the scientifically allowable total catch, allocation of a percentage share of that total to fishermen can be set to the level of our calculated optimal outputs each region/fisherman.

Measures for excess capacity of fishing fleets, more specifically, capacity output and Capacity Utilization (CU), are often applied in the literature. Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology, and capacity output represents the maximum level of production the fixed inputs that it could be expected to produce under normal working conditions (see Johansen, 1968; Morrison, 1985; Färe et al., 1994; FAO, 2003; Kirkley et al., 2003; FAO, 2008a). CU is the proportion of available capacity that is utilized, and is usually defined as the ratio of actual (i.e., current) output to some measure of capacity (i.e., potential) output (see Morrison, 1985; Nelson, 1989; FAO, 2003; Kirkley et al., 2003; FAO, 2008a). Therefore, CU is measured on a 0 to 1 scale. When CU is less than 1, one could produce more catch than current catch if inputs are fully utilized. In other words, smaller inputs are enough (assuming they are fully utilized) to produce same level of current catch.

There have been many studies focusing on fishing capacity and measured the capacity output and CU for decades. Assesment methods for estimating CU are classified roughly into two groups, which are parametric methods and non parametric methods. As a case of using parametric methods, Kirkley and Squires (1988) provided an hedonic cost function approach for estimating the

[‡] The allocated shares are bought and sold like shares of stock in a company. Shareholders in the fishery are each guaranteed a percentage of the catch. The number of fish that each fisherman may catch is usually based on past averages. The catch share systems are already common in Australia, New Zealand and Iceland, while they have been gaining popularity in Canada and the United States. Though our model directly shows how much each individual needs to catch (and use as effort), we do not allow market mechanism in the model. In this sense, it is different from the catch shares concept. However, we are able to show optimal individual catch combinations, so that total catch is divided to each catch share.

aggregate capital stock and investment in a fishery utilizing the limited information. They used vessel acquisition price and vessel characteristics in New England from 1965 to 1981. Although these data had several limitations, the results indicated that the investment in New England fisheries apper to had increased over time. The largest increase in investment occurred in 1979 after the passage of the Magnuson Fisheries Conservation and Management Act of 1976.

Similarly, Asche et al. (2008) also adopted a parametric approach, which includes cost and profit functions, with their survey data of cost and earnings. They investigated potential rents and overcapacity of five case studies in Norway, Sweden, Denmark and the United Kingdom, which apply individual vessel quota system, and in Iceland, which implements the ITQ system. Based on their cost and earnings data, the actual level of economic profits in most of these fisheries except for Iceland was found to be negligible. However, the results show more than half of the vessels were estimated to be potentially redundant, and potential economic profits were estimated to be between 22% and 61% in all case studies.

As another case using parametric approaches, Felthoven and Morrison Paul (2004) developed a multi-output and multi-input stochastic function framework considering changing output compositions at full capacity in order to estimate capacity output and CU. They applied the model to catcher-processor vessels in the Alaskan pollock fishery. The average capacity utilization measure in 2001 range from 0.65 for a scenario of flatcatch held constant to 1.1 for a scenario assuming unrestricted output compositions. The former implied that the pollock catch could increase on average by about 53% with the same level of flatfish landings. The latter suggested economic optimization over outputs would result in less pollock being caught. They also found that for many vessels there is a divergence between the output price ratio of pollock to flatfish and the marginal rate of transformations, i.e. output trade-offs.

In addition, there are also a lot of cases using non parametric approaches, which are usually Data Envelopment Analysis (DEA), to estimate capacity output and CU. As a case using non parametric approaches, Tingley and Pasco (2005) estimated CU of four UK fleet segments using DEA model following Färe et al. (1989, 1994), and examined some factors effecting CU with tobit regression analysis. The results indicate that average CU of otter trawling vessels, beam trawling vessels, scallop dredging vessels and gill netting vessels in the UK fisheries are 0.88, 0.67, 0.78 and 0.70, and they could increase their outputs by 14%, more than 50%, 28% and 43%, respectively. The results of the tobit analysis suggest that changes in stock abundance are the main factor affecting CU, although the overall statistical quality of the models was poor.

Based on Färe et al. (2001), whose models are used by Tingley and Pasco (2005) as noted above, Kerstens et al. (2006) has developed a sophisticated model of the multi-output/input frontier-based short-run Johansen industry model. In the industry model, capacities of individual fishery entities are utilized by minimizing fixed industry inputs given their total outputs, capacities and the current state of technology, assuming the variable inputs are allowed to vary and be fully utilized. They adopted the industry model to analyze capacity outputs of the Danish fleets, extending to scenario analyses of tightening quota, seasonal closure policies, lower and upper bounds, decommissioning schemes and area closures. The results show that vessel numbers can be reduced by about 14 % and the use of fixed inputs by around 15%, depending on the specific objective and policy mix in the Danish fishery.

The more detailed purpose of this study is to measure the capacity output and CU of Japan’s fisheries. Then, we examine how much cost reductions they can achieve in a well-controlled world using unique disaggregated data covering all areas in Japan. We also aim to find the optimal inputs/outputs mix of Japanese fisheries given fisheries quota. It is also important to recognize how much capacity will be needed when apparently too loose TAC system at present tightens up. This estimation provides an economic vision for the fisheries market through the TAC system, and offers criteria for stringency of quota enforcement. In addition, we consider technical inefficiencies due to the differences in fisheries areas and fishing types under different conditions and variant distributions of fish stocks.

In this study, we apply the revised Johansen industry model to measure the capacity outputs following Kerstens et al. (2006). This model consists of two steps of different linear programming (LP) techniques. First, we measure the capacity output by using output-oriented DEA. Second, we measure the optimal fixed inputs given in certain fishery quotas. Optimal scales of outputs and fixed factor inputs indicate the required total outputs and inputs at industry level. Calculated loss of efficiency shows the possible reduction of the fixed inputs. The capacity outputs assume variable return to scale (VRS) in our model to be flexible. The production frontier is calculated based on the maximum outputs given current inputs.

Data used in this study comes from *the 11th Fishery Census of Japan on 2003* and *Annual Statistics of Fishery and Fish Culture 2003* by Ministry of Agriculture, Forestry and Fisheries of Japan. The data sets are composed of each aggregated fishery entity per municipality per marine fishery type in the whole of Japan, and contain a wealth of data at the whole industrial level, which other databases seem not to have. The data include production value, gross registered tons and horse power (kilowatt) of the vessels and the number of fishermen and fishing days, and we estimate production quantities from the data of production value. There are no cost data about the fisheries. Therefore we estimate roughly the cost data to examine the potential cost reduction.

However, an interpretation problem occurs in using the census data since the data does not provide individual data per vessel. Capacity output and CU in this study are estimated not per vessel as defined in previous studies, but per municipality per marine fishery type. For this reason, the interpretation of the analysis in this study is different from that of the analysis the previous studies generally used.

Although the interpretation problem remains, the estimation of capacity output and CU using the Census data would be beneficial since little studies estimated capacity output and CU in the Japanese fishing industry. At this time an easy-to-access individual data per vessel at the whole industry level seems not to be build. This study would provide only a little ballpark quote, but help us to see the picture of the actual condition in the fishing industry in Japan.

2. Model

2.1. Industry Model

Following the revised short-run Johansen model of Kerstens et al. (2006), we compute marine fishery efficiencies in Japan. The conceptual model proceeds in two steps. In the first step, the capacity measure is compared to determine capacity production for each fishery entity at the production frontier. The capacity production is calculated by output-oriented DEA model assuming strong disposal of inputs and outputs, and variable returns to scale. In the second step, individual entity capacities are utilized with the minimization of fixed industry inputs given total outputs, capacities, and current state of technologies. This capacity measure is short-run because it does not assume any change in the existing firm-level capacity, and it is a technical rather than an economic capacity notion.

The following models are applied in this study. The production technology S transforms inputs $x=(x_1,...,x_n)\in R_+^n$ into outputs $u=(u_1,...,u_m)\in R_+^m$ and summarizes the set of all feasible input and output vectors: $S=\{(x,u)\in R_+^{n+m}: x \text{ can produce } u\}$. Let J be the number of regional units. The n-dimensional input vector x is partitioned into fixed factors (indexed by f) and variable factors (indexed by v): $x=(x_f,x_v)$. To determine the capacity output and CU, a radial output-oriented efficiency measure is computed relative to a frontier technology providing the potential output given the current inputs use: $E^0(x,y)=\max\{\theta:(x,\theta y)\in S\}$.

Plant capacity output is defined as the maximum amount that can be produced per unit of time with existing equipment (given the availability of variable factors of production is not restricted). The term 'plant' capacity is used as this is a basic model. Indeed, boat capacity is estimated in this step. In the context of fisheries, this definition corresponds to the maximum catch a vessel can produce if present technology is fully utilized given the biomass and the age structure of the fish stock. We note that this definition does not measure the capacity output level that can only be realized at prohibitively high cost of input usage (and hence be economically unrealistic). This is because this plant capacity measure does not allow reallocation of inputs and outputs across firms, and implicitly assumes that production of capacity output is feasible and that the necessary variable inputs are available. The production technology $\hat{S}$ of plant capacity can be represented:

$$\hat{S}^{\text{VRS}} = \left\{ (x,u) \in R_{+}^{N+M} : u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm},\ m = 1,...,M; \right.$$
$$\sum_{j=1}^{J} z_j x_{jf} \leq x_{jf},\ f = 1,...,F; \tag{1}$$
$$\left. \sum_{j=1}^{J} z_j = 1, z_j \geq 0,\ j = 1,...,J \right\}$$

The output-oriented efficiency measure θ_1 is measured by the following LP problem for each firm j (j =1, 2, …, J) relative to the short-run production possibilities set:

$$\max_{\theta_1^j, z_j} \{\theta_1^j : (x, \theta_1^j u) \in \hat{S}^{\text{VRS}}\} \quad . \tag{2}$$

To be consistent with the plant capacity definition, only the fixed inputs are bounded at their observed level and the variable inputs in the production model are allowed to vary and be fully utilized. The computed outcome of the model is a scalar θ_1. The θ_1 shows by how much the production of each output of each region can be increased. In particular, capacity output for region k of the mth output is θ_1^{*k} multiplied by actual production; u_{km}. Therefore, capacity utilization based on observed output (subscripted 'oo') is as follows:

$$\mathrm{CU}_{\mathrm{oo}}^{k} = \frac{1}{\theta_1^{*k}} \quad . \tag{3}$$

This ray CU measure may be biased downward (see Färe et al., 1994). This is because there is no guarantee the observed outputs are not produced in a technically efficient way. The problem of technically efficient measure is solved given that both the variable and fixed inputs are constrained to their current level. Another technical efficiency measure is obtained by evaluating each region j = 1, 2, ..., J relative to the production possibility set S^{VRS}:

$$\begin{aligned} S^{\mathrm{VRS}} = \Big\{ &(x,u) \in R_{+}^{N+M} : u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm},\ m = 1,\ldots,M; \\ &\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn},\ n = 1,\ldots,N;\ \sum_{j=1}^{J} z_j = 1, z_j \geq 0,\ j = 1,\ldots,J \Big\} \end{aligned} . \tag{4}$$

The outcome (θ_2) shows by how much production can be increased using the technically efficient inputs:

$$\max_{\theta_2^j, z_j} \{ \theta_2^j : (x, \theta_1^j u) \in S^{\mathrm{VRS}} \} . \tag{5}$$

The technically efficient output vector is θ_2 multiplied by observed production for each output. The technically efficient output (subscripted 'eo'), or unbiased ray measure of capacity utilization, is calculated as:

$$\mathrm{CU}_{\mathrm{eo}}^{k} = \frac{\theta_2^{*k}}{\theta_1^{*k}} . \tag{6}$$

Such a ratio is suggested to be unbiased in the sense that it is not directly influenced by measured technical inefficiency (Färe et al., 1989; Felthoven and Morrison Paul, 2004). Even if the production inefficiency were mismeasured, this tends to cancel out upon taking the ratio since the mismeasure is included in both the numerator and denominator (Holland and Lee, 2002).

We focus on reallocating catches between vessels by explicitly allowing improvements in technical efficiency and capacity utilization rates. The model is developed in two steps as follows. An optimal activity vector z^{*k} is provided for region k from model (1), and thus capacity output and the optimal use of fixed and variable inputs are computed in the first step:

$$u_{km}^{*} = \sum_{j} z_j^{*k} u_{jm} - s_{jm}^{*k};\ x_{kf}^{*} = \sum_{j} z_j^{*k} x_{jf} + s_{jf}^{*k};\ x_{kv}^{*} = \sum_{j} z_j^{*k} x_{jv} \tag{7}$$

where s_{jm}^{*k} and s_{jf}^{*k} are the optimal surplus and slack variables corresponding to the output, respectively, fixed input dimensions. In a second step, these 'optimal' frontier figures (i.e., capacity output and capacity variable and fixed inputs) at regional level are used as parameters in the industry model. Particularly, the industry model minimizes the industry use of fixed inputs in a radial way such that the total production is at least the current total level (or at a quota level in the model extended later) by a reallocation of production between regions. Reallocation is allowed based on the frontier production and input usage of each region. In the short run, we assume that current capacities cannot be exceeded either at the regional or industry level. Define U_m as the industry output level of output m and X_f (X_v) as the aggregate fixed (variable) inputs available to the sector of factor f (v), i.e.:

$$U_m = \sum_{j} u_{jm},\ X_f = \sum_{j} x_{fj},\ X_v = \sum_{j} x_{vj}\ . \tag{8}$$

The formulation of the multi-output and frontier-based industry model can then be specified as:

$$\begin{aligned}
&\min_{\theta, w, X_v} \theta \\
&\text{s.t.} \sum_{j} u_{jm}^{*} w_j \geq U_m,\ m = 1,\ldots,M, \\
&\qquad \sum_{j} x_{fj}^{*} w_j \leq \theta X_f,\ f = 1,\ldots,F, \\
&\qquad -X_v + \sum_{j} x_{vj}^{*} w_j \leq 0,\ v = 1,\ldots,V, \\
&\qquad 0 \leq w_j \leq 1,\ \theta \geq 0,\ \ j = 1,\ldots,J.
\end{aligned} \tag{9}$$

2.2. Extension of Industry Model

We turn to the second-stage industry model (9). First, following the second modification above, the constraints for each output dimension have to reflect the fact that production may take place in different areas. That is, there are M output constraints (species) for each of the A areas:

$$\sum_{j} u^{*}_{jma} w_{ja} \geq U_{ma},\ m = 1,...,M, a = 1,...,A\ . \tag{10}$$

In general, the optimal activity vector w represents a weight assigned to the vessel's peers in order to estimate its capacity output. However, the data in this study is composed of each municipality data per fishery type. Therefore, the optimal activity vector in this study denotes a weight allocated for each municipality to estimate each municipal capacity in each fishery.

Each region j has one area a because the area corresponds to the place each aggregated entity belongs. Second, the industry consists of fishery entities or vessels fishing in different areas. The constraints for each of the total fixed inputs can be formulated in a most general way in terms of constraints indexed by area:

$$\sum_{j,a} x^{*}_{fja} w_{ja} \leq \theta X_{f},\ f = 1,...,F. \tag{11}$$

Third, the constraints on the variable inputs are:

$$-X_{v} + \sum_{j,a} x^{*}_{vja} w_{ja} \leq 0,\ v = 1,...,V. \tag{12}$$

To offer a menu of current and potential conservation and distributional policies in fisheries, we add some further refinements to the short-run industry model of Dervaux et al. (2000). We here focus on four issues: (i) tightening quotas of either species and (ii) partial tolerance of technical inefficiencies.

(i) We consider setting quotas such as TAC for particular species in Japan in order to illustrate how much capacity is necessary given a certain amount of quota. We simply add the constraint:

$$\sum_{a} U_{ma} = U_{m} \cdot Q_{m},\ \ m = 1,\ 0 \leq Q_{m} \leq 1 \tag{13}$$

given that the species are indexed by m equal to 1 (i.e. the first output). Q_m indicates a quota rate for the mth current industry output. In this study Q_m is incremented by 0.01 from 0 to 1 for sensitivity analysis purpose.

(ii) The frontier nature of the underlying technologies may push things too far so that it is practically impossible to require vessels to adjust immediately to technically efficient production plans. While technical efficiency is a condition for any social optimum, realistic planning procedures may require tolerating technical inefficiency for part of this path for informational and political reasons (Peters, 1985).

This can be modeled by adjusting the capacity output, which enter to the second stage industry model, by its current observed technical inefficiency and ultimately corrected by an efficiency improvement imperative (α) (see Kerstens el al., 2006). Of course, technically efficient regions at present need no such adjustment. Therefore, assuming this correction factor is smaller or equal to unity ($\alpha = 1$), adjustment of the second stage capacity output could take the following form when technical inefficiency is (partially) accepted:

$$\begin{aligned} &\theta \geq 0,\ \ \hat{u}^*_{jma} = \frac{u^*_{jma}}{\max\{1, \alpha\theta^*_1\}}\ . \\ &j = 1,\ldots, J,\ \ a = 1,\ldots, A \end{aligned} \tag{14}$$

In this research α is 0.1 or 0.2 for all the entities when technical inefficiencies are tolerated partially. When α is set to be 0.1 or 0.2, capacity outputs of all the entities is limited up to 10 or 5 times of current output.

We sum up the above mentioned constraints and our model is shown as follows:

$$
\begin{aligned}
&\min_{\theta, w, X_v} \theta \\
&\text{s.t.} \sum_j \hat{u}^*_{jma} w_{ja} \geq U_{ma}, \ m = 1, \ldots, M, \ a = 1, \ldots, A \\
&\quad \sum_{j,a} x^*_{fj} w_{ja} \leq \theta X_f, \ \ f = 1, \ldots, F \\
&\quad -X_v + \sum_{j,a} x^*_{vj} w_{ja} \leq 0, \ \ v = 1, \ldots, V \\
&\quad \sum_a U_{ma} = U_m \cdot Q_m, \ m = 1 \\
&\quad \theta \geq 0, \ \ \hat{u}^*_{jma} = \frac{u^*_{jma}}{\max\{1, \alpha \theta^*_1\}} \\
&\quad j = 1, \ldots, J, \ \ a = 1, \ldots, A, \ 0 \leq w_{ja} \leq 1, \ 0 \leq Q_m \leq 1.
\end{aligned}
\tag{15}
$$

3. Data and Scenarios

3.1. Data

Data used in this study comes from *the 11th Fishery Census of Japan on 2003* and *Annual Statistics of Fishery and Fish Culture 2003* by Ministry of Agriculture, Forestry and Fisheries of Japan. The data set is composed of each aggregated fishery entity per municipality per marine fishery type in Japan. The *2003 Fishery Census of Japan* was conducted to clarify the structures of fishery production in Japan, and to comprehend the overall background of fisheries concerning fishing villages, marketing and processing industries among others. The purpose is developing basic data for fisheries policies including improvements in the structure of fisheries.

Our output data is production value (in the unit of Japanese yen) and quantities data. There are nine types of outputs used in this study, including total production quantity, all fishes, the other marine animals, Japanese sardine, Japanese jack mackerel, Mackerel Pacific saury, Alaska Pollock, queen crab, and Japanese common squid (Table 1). The TAC system in Japan applies to all these seven species. For example, the Squid showed a slight decline although it still remains in a dominant position. The Pollock has been on the decline mainly due to the subsequent fall of catch in the Bering high seas. Mackerel have also decreased drastically over the years.

There are two variable inputs - labor and fishing days - and two fixed inputs of gross registered - tons (Grt) and horse power (kilowatt) - for aggregated fishery entities of each municipality and marine fishery type in Japan. The fixed inputs are both multiplied by the number of fishing days, following Kerstens et al. (2006). The variable inputs are numbers of workers on board at peak times and average fishing days of each aggregated entity. These data cover effectively all the Japanese fishery entities. The aggregated fishery entities with missing values and fishing within 30 days are excluded in the sample. In total, 74,728 fishery entities are covered in the data set of 7,483 observations. Total product value of these data accounts for 89.3% of the original data in the Census. On average, each aggregated fishery entity consists of about 10 entities (Table 1). We have 39 classifications of marine fisheries in analyses. Basic allocation of fishery in each are, technology type, and fishery species. Small whaling, diving apparatus fisheries, shellfish collecting, seafood collecting, and other fisheries are excluded because we consider these fisheries atypical cases.

We assume management decisions are provided in the disaggregated regional level, especially models (1) and (4), because their decision making is applied to one given area and one given fishery type. Thus, the efficiency of each aggregated fishery entity is evaluated relative to one of the potentially 351 different technologies (nine areas by thirty-nine marine fishery types). The technologies, which consist of only a few similar observations, may lead to biases in the estimation of plant capacity due to a lack of comparable production units. To avoid downward estimation, we use 10 large classifications and refer to the 10 and 39 fishery classifications as fishery type 1 and 2, respectively (see Table 1). Therefore, there are potentially 90 and 351 different technologies in fishery type 1 and 2. We use mainly fishery type 1, and compare type 1 with type 2 in an unconstrained scenario.

3.2. Scenarios

In each specification, we apply several different types of output variables. In the first two specifications, production value and production quantity are used as the output variables, respectively, and we compare both efficiencies. Second, we divide the estimated production quantity into two and three categories, which are (a) TAC species and the others including (b) fish and (c) the other marine animals. The aim of this division is to set production quotas only for respective TAC species, and to compare the efficiencies of each group.

We classify a series of scenarios, systematically testing the effect of additional constraints. The results of several policy-oriented scenarios with various constraints are useful for policy implications. These scenarios are summarized in Table 2. Basic scenario 1 is the basic industry model without any particular constraints, and use fishery type 1. Basic scenario 2 uses fishery type 2 without any particular constraints. The tolerated technical inefficiencies scenario allows for technical inefficiencies, but already imposes improvement imperatives of 1,000 and 500 per cent (thus, $\alpha = 0.1$ and 0.2). We compute the optimal inputs in the industry model implementing the 100 percent quota of current outputs, which is, in other words, no quota constraint (i.e. $Q_1 = 1$ in equation (13)), at each technical inefficiency value.

We also estimate optimal fishery expenditures at current 100 percent quota to understand how much expenditures could be reduced in a reallocated world. We focus especially on four kinds of expenditures, such as vessels, implements, oil costs and wage costs, which appear to change as the amounts of fisheries inputs vary. However, we have only the production value data as mentioned above. Therefore we estimate roughly the fisheries expenditures relating to the marine fisheries operations referring to the production value and the optimal inputs at current 100 percent quotas.

We use the number of marine fisheries entities and the average fishery income and expenditures by type of organization categories and total fishery income of fishery households and the whole of industry from *the 11th Fishery Census of Japan on 2003* and *Report of Statistical*

Survey on Fishery Management on 2003 (Table 3). We figure in only four kinds of organizations, which are individuals (family operations and employment operations), firms and Joint management to calculate the fishery income and expenditures of the whole industry, and except the others since we have no detailed earnings statements of these and the numbers of entities in these fishery organizations are low. We compute the numbers of entities of the family operations and the employment operations by the total fishery income of fishery households, and estimate the fishery income and expenditures of the whole fishing industry in Japan. Although there are indeed a little difference between the realistic value and the estimated value in total fishery income, total estimate values of vessels, fishing gears, oil, wage and cost depreciation are 3.7%, 3.2%, 11.8%, 25.7% and 8.4% of the total estimated fishery income, respectively.

In regard to wage, however, there is an interpretive problem since wage means somewhat different things to different categorical groups. For fishery establishments and fishery companies, the corporate bodies would receive the fishery profits and would pay to the fishermen as wage. For fishery households with family operations, the fishery profit would be a form of wage as their income. We set the fishery profit stay disjoined from wage for all DMUs since we could not divide DMUs into fishery households and others.

First, in order to estimate cost reduction in the scenario analyses, we simply multiply total fishery income of the sample data, i.e., 932.2 billion yen, by the fishery expenditure ratios estimated above, and the total estimated expenditures of vessels, fishing gears, oil, wage and cost depreciation in the sample are 34.1 billion yen, 29.5 billion yen, 110.2 billion yen, 239.2 billion yen and 78.2 billion yen, respectively. Second, we assume that the expenditures of vessels and fishing gears correlate with the efficiency score, i.e., θ in equation 15, that the oil costs correlate with the optimal use of tonnage multiplied by that of fishing days at current 100% quota, i.e., $\sum (w_j \cdot x^*_{f,1}) \cdot (w_j \cdot x^*_{v,1})$, and that the wage costs relate to the optimal use of labor multiplied by that of fishing days at current 100% quota, i.e., $\sum (w_j \cdot x^*_{v,1}) \cdot (w_j \cdot x^*_{v,2})$. In order to estimate the expenditures, we multiply the estimated expenditure of vessels (which includes vessels and fishing gears), oil and wage in the 1st step by θ, $\sum w_j^2 \cdot x^*_{f,1} \cdot x^*_{v,1} \big/ \left(X_{f,1} \cdot X_{v,1}\right)$ and $\sum w_j^2 \cdot x^*_{v,1} \cdot x^*_{v,2} \big/ \left(X_{v,1} \cdot X_{v,2}\right)$, respectively.

4. Empirical Results

4.1. Scenario Analyses

(a) Current and Capacity Outputs

Scenarios 1 and 2 show the results comparing current output and capacity outputs (see Figure 2). In the figure, vertical and horizontal axes represent percentages of total production values and fixed inputs, respectively. The results are calculated with LP and show how much production *values* fixed inputs can maximally produce based on each scenario. Similarly, Figure 3 shows how much production *quantities* the fixed inputs can maximally produce based on each scenario.

The results indicate that there is a large excess capacity in Japanese fisheries. This reflects the fact that fisheries management is in a state of crisis. Since access is almost free, fishing activity is under-priced and therefore a huge amount of effort is devoted to fishing. When there are no differences among efficiencies of the aggregated entities, 1% of total fixed inputs produces 1% of total outputs, and the path of the current output will be linear. Note that efficiency implies average efficiency of each scenario if we do not specify otherwise. This is because current output is calculated with LP, which seeks combination of DMUs to minimize a requisite amount of the fixed inputs for a certain amount of output. On the other hand, the more varied efficiencies of each aggregated entity are, the more curved the line of capacity outputs since 1% of total outputs can be produced by less than 1% of fixed inputs.

Compared with the difference between current outputs of the production values and quantities, the current output of the production values has a less curved line than that of the quantities. It implies that each DMU decides the amounts of fixed inputs depending on expected values rather than expected quantities, and it is legitimate decision-making depending on estimation of income and expenditure of each fishery entity.

Compared with the difference between capacity outputs of the production values and quantities, the capacity outputs of the production values are smaller than those of the quantities. The difference between these numeric values may result from the difference of the degrees of varied efficiencies based on the entities' valid decision-makings with cost benefit considerations.

(b) Capacity Outputs

We show two results of the efficiencies using the production value data and the quantity data. First, Figure 4 shows capacity outputs of production values based on each scenario. Sensitivity analyses are provided by changing total quota, and, in each case, efficiency is computed. The quota is used as the horizontal line in the figure. Here, efficiency in this figure is defined as a reduction percentage of fixed inputs by applying equation 15.

According to the results, efficiencies based on 100% of production values (i.e., current level of production) as total quota are 0.102 in the basic scenario 1, 0.169 in the basic scenario 2. In the scenarios at current 100% quotas considering technical inefficiencies up to 10 and 5 times, the efficiency scores 0.156 (0.239) and 0.210 (0.292) are in the scenarios using fishery type 1 (type 2), and the efficiency scores declines by approximately 5 percent at regular intervals as α varies from 1 to 0.1.

Second, Figure 5 shows capacity outputs of computed product quantities based on each scenario. The results show efficiencies at 100% quota are 0.072 and 0.130 in the basic scenario 1 and

2, respectively. These scenarios are relatively efficient and similar to those of the production value. In the scenarios at current 100% quotas considering technical inefficiencies up to 10 and 5 times, the efficiency scores 0.96 (0.170) and 0.125 (0.197) are in the scenarios using fishery type 1 (type 2), and the efficiency scores declines by about 2.5 percent at regular intervals as α drops from 1 to 0.1.

(c) TAC species

We show results of sensitive analyses by only imposing quota on all TAC species. First, Figure 6 shows the result where the total product quantities are separated into two variables of all TAC species and non-TAC species. The efficiency scores at 100% quota are 0.109 and 0.169 in the basic scenario 1 and 2, respectively. In addition, the paths of each scenario curve alongside each other and are approximately parallel. In the scenarios at current 100% quotas considering technical inefficiencies up to 10 and 5 times, the efficiency scores 0.135 (0.205) and 0.168 (0.231) are in the scenarios using fishery type 1 (type 2), respectively, and the efficiency scores declines by about 3 percent at regular intervals as α varies from 1 to 0.1.

Second, Figure 7 shows the result using data that the total product quantities are divided into three variables: TAC species, other fish and other marine animals. The paths of each scenario are also approximately parallel alongside each other. Efficiencies at 100% quota are 0.145 and 0.190 in the basic scenario 1 and 2, respectively. In the scenarios at current 100% quotas considering technical inefficiencies up to 10 and 5 times, the efficiency scores 1.77 (0.222) and 0.204 (0.246) are in the scenarios using fishery type 1 (type 2), respectively.

Then, we provide the results that only impose quota on each of six TAC species. First, Figure 8 shows the result using two variables, 1) the six TAC species and 2) one other, into which the estimated product quantities are divided. At 100% TAC quota efficiencies in the scenarios of Japanese sardine, Japanese jack mackerel and Mackerel are 0.086, 0.088 and 0.089, respectively, and the efficiency paths of these species scenarios vary slightly as each TAC quota decreases. At 100% TAC quota efficiencies in the scenarios of Pacific saury, Alaska pollock and Japanese common squid are 0.093, 0.099, and 0.099, respectively. The efficiency paths vary more than the results of the others as each TAC quota decreases. The efficiency of the queen crab scenario is 0.084 at 100% TAC quota, and the efficiency path shows the highest path among all the scenarios.

In contrast, the efficiency of basic scenario 1, imposing quota on total quantities of all TAC species, is 0.109 at the quota of current industry level. The score is the most inefficient among all the scenarios. This suggests that there are fewer options to choose activity vectors of the aggregated entities to satisfy quota of each TAC species. In this case, quota is imposed only on a certain TAC species and, therefore, the other fishery quantities have capacities to catch 100% of current outputs. Therefore, options to choose fixed input factors given that quota imposing on TAC species are fewer and the efficiency paths change more horizontally.

Second, Figure 9 shows the results using each of six TAC species, other fish, and other marine animals. Efficiencies at 100% quota are 0.109 in the Japanese sardine scenario, 0.110 in the Japanese jack mackerel scenario, 0.112 in the Mackerel scenario, 0.118 in the Pacific saury scenario, 0.117 in the Alaska pollock scenario, 0.108 in the queen crab scenario, 0.139 in the Japanese common squid scenario, and 0.145 in the all TAC species scenario. The efficiency paths of the Japanese sardine and queen crab scenarios are the lowest efficiency paths, and that of the all TAC species scenario is the most inefficient, likewise the path using two variables above. The most scenarios of each TAC species are at less than 60% of each quota.

These varied efficiencies depend on the selection of outputs. When each output in each category is separated in different model, the efficiency score will become even lower. It is difficult to measure the efficiencies of each fishery method because there are many fishery species in the Japanese sea and many fishery methods developed in the same regions. While we can estimate efficiencies in various detailed cases using more disaggregated categories, it will become difficult to discuss entire fisheries in Japan. The opposite is also true. Based on the results, the efficiency paths are approximately the same among the cases, which vary only in quotas of each TAC species.

In summary, ensuring the current capacity outputs, except of certain TAC species, the fixed inputs can satisfy the capacity outputs for the TAC species. Regarding the capacity outputs of total quantity per fishery area in the basic scenario 1 and 2, the most efficient area is the Pacific Ocean in the north. Most areas have excess capacities of more than 100% in basic scenario 2. This implies that there are fixed inputs, which can produce more than twice of the current quantities in Japan.

The fisheries with the lowest excess capacity are those for Pacific saury. There are excess capacities of 39.0% and 38.9% on Pacific Saury using the two and three variables divided above (fishery type 1). The most inefficient fisheries are those for Japanese common squid, and there are excess capacities of 212.3% and 205.2%.

(d) Capacity Utilization

We estimate CU_{oo} and CU_{eo} of total production value and quantity in the basic scenario 1 and 2. Table 4 presents simple average CU_{oo} and CU_{eo} among aggregated entities, which are not weighted average values, classified by fishery type 1 and 2. There are significant differences in the value of CU_{oo} and CU_{eo} among the fishery types.

In the basic scenario 1 using estimated quantity data (specification 3 and 4), the fisheries with the highest average CU_{oo}, i.e., $CU_{oo} = 1$, is large trawls in East China sea, large and medium surrounding net of one-boat operation catching skipjack and tuna on distant water, and two-boats operation with purse seine (fishery type 2:(2), (11) and (14)). In specification 3, the fishery with the lowest average CU_{oo} is anglings (fishery type 1:(10)), and the CU_{oo} is 0.113.

In the specification 4 the fisheries with the highest average CU_{eo}, i.e., $CU_{eo} = 1$, is large trawls in East China sea, large and medium surrounding net of one-boat operation catching skipjack and tuna on distant water and off-shore water, two-boats operation with purse seine, and squid angling on distant water (fishery type 2:(2), (11), (12), (14) and (34)). In specification 4, the fishery with the lowest average CU_{eo} is squid angling on coastal water (fishery type 2:(36)), and the CU_{eo} is 0.486.

The difference between CU_{eo} and CU_{oo} shows the degree of random variation in catch and technical inefficiency, which is not producing the full potential given the level of both fixed and variable inputs. The fisheries with lowest differences between CU_{eo} and CU_{oo}, i.e. $CU_{eo} - CU_{oo} = 0$, are distant water trawls, large trawls in East China sea, large and medium surrounding net of one-boat operation catching skipjack and tuna on distant water, two-boats operation with purse seine and billfish drift gill net (fishery type2: (1), (2), (11), (14) and (19)). The fishery with the highest differences between CU_{eo} and CU_{oo} is anglings (fishery type 1: (10)), and the difference value is 0.459.

4.2. Reducing the Number of Fishery Entities

We compute the amount of non-zero activity vectors w from the results above and provide the optimal numbers of the aggregated fishery entities at current 100% quota per sea area around Japan. Among all the scenarios using the quantities data of 7,483 entities in our sample, the optimal total number of fishery entities at 100% quota, are as follows; (1) 1,167 at a minimum in the technically tolerated inefficiency scenario up to 10 times using one variable output, (2) 2,692 at a maximum in the technically tolerated inefficiency scenario up to 10 times using the three variable outputs.

On average the optimal total DMU numbers are about 2,000. The values of the activity vectors are almost at upper limits among all the scenarios (i.e., all inputs are utilized). We compute the numbers of fishery entities, which is 74,727 in the overall sample, by multiplying the active vector values and the numbers of entities in each aggregated entity level. The minimum number is 4,974.7 in the basic scenario 1 using the quantities data of one variable output. The maximum number is 21,184.7 in the basic scenario 2 using the production value data allowing technical inefficiency up to 5 times of each current output.

We notice there are large differences among the optimal sizes of fishery entities in each scenario at 100% quota. On average, however, the optimal size of the current Japanese fisheries fishing the amount of current production value/quantity is about one third of current size. In other words, one third of the current fishery entities are required even if the central government implements fishery policies in the most efficient way.

4.3. The Optimal Input Levels

We compute the optimal amounts of inputs at current 100% quota in each scenario. In each scenario at current 100% quota, the optimal input values of gross registered tons and horse powers (kilowatt) are equal to each efficiency score, i.e. θ. In each similar scenario, we set the average optimal fishing days as simple average $w_j \cdot x^*_{v,1}$ among DMUs with $w_j \neq 0$, and the optimal number of fishermen as $\sum w_j \cdot x^*_{v,2}$.

In the basic scenario 1 and 2 using the production value data at 100% quota, the average optimal number of the fishing days are 113.32% and 112.72% of the current average fishing days on board, and the total optimal number of fishermen are 35.69% and 43.81% of the current, respectively. In the technical inefficiency scenarios allowing capacity outputs to be up to 10 and 5 times of current outputs using the production quantity data with fishery type 1 (type 2), the average optimal number of the fishing days are 119.43% (114.81%) and 120.45% (116.50%) of the current average fishing days on board, and the total optimal number of fishermen are 41.62% (53.83%) and 48.59%

(58.45%) the current, respectively. In summary, in each scenario at 100% quota, the optimal use of the number of the fishermen and the average fishing days are about 40% and 120% of current condition.

Going through the amounts of the optimal inputs in each fishery type, we see that allocating the fishery types in the most efficient way is different over specific fishery types. In addition, a fishery type with a large amount of optimal inputs may not be an efficient method itself, but a method with large capacity outputs from optimal inputs based on the first step revised industry model. Relatively large amounts are types of surrounding nets (4), lift nets (6), fixed nets (7) among others, and long lines (9) especially are utilized little.

4.4. Estimates of Cost Reduction

We compute the fishery expenditures of each scenario in Table 5. Overall, required costs of vessels, fishing gears and oils (in our computed cases) are mostly less than about 20 percent of current costs, and the wages and total costs are mostly about 40 and 30 percent, respectively. In the basic scenario 1 (basic scenario 2), using one output variable of the production value, what we need as costs of vessels and fishing gears, oil, wages and total are 10.21% (16.93%), 11.99% (19.31%), 35.26% (44.14%), and 25.20% (33.33%), respectively.

The reduction in total number of fishing vessels represents a large amount of reduction in total cost in the long run. These significant potential results are important for policy purpose. In the basic scenario 1 (scenario 2) using the production value data, the results imply that the current estimated fishery profit (total 133.3 billion yen) will be increased to 442.2 (408.6) billion yen. In addition, the fishery profits would be more increased since the amount of the cost depreciation relating to the fishery operations, which are leave out of consideration, would be decreased in the long run.

5. Discussion and Conclusion

In this paper we examine capacity output and CU of the marine fisheries in whole of Japan. As a result, in Japan, the maximum level of production the fixed inputs are capable of supporting (i.e., capacity output) could be more than three times larger. Estimated CUs vary greatly by each marine fishry, and current overall fixed inputs could be reduced to one-tenth. The fishery profits could be increased up to about 3 times. In addition, central government plans could reduce to one-third aggregated fishery entities maintaining the capacity output to ensure the total fishery catch. Getting rid of these inefficient fishers would help lead to profitable and sustainable exploitation fishery management. Furthermore, a government-backed industry development program would need this type of change. These results are much larger than the potential of Denmark as reported in studies by Kerstens et al. (2006). These differences are caused by the large divergence of fishery management level (or efficiency).

This study does not discuss both input and output control. Political factors are often in favor of input-oriented approaches to managing fishery. However, there appears to be increasing acceptance of output-oriented controls to manage catches of target fishes (Holland, 2007). Though our approach is not a market-based approach, we try to show the expected outcome using output-oriented controls. For the output-oriented controls be worked inexpensively, improvements in remote automated monitoring technology need to increase the feasibility and then diminish the cost of outcome-control. Our study shows that there are many inefficient fishery entities, and implies that many of these inefficient fishermen are not able to survive in the market in perfect competition.

Apparently, the amounts of subsidies, such as buyback programs, need to be increased so that inefficient fishermen could exit the fishing industry smoothly. However, higher government subsidies of the sort should be carefully considered to be implemented. Simple buyback programs that purchase inefficient vessels out of the fishery will not help to solve the overcapacity problem (Holland et al., 1999; Clark et al., 2005; Asche et al., 2008). First, the buyback programs may at best remove only a marginal portion of the fishing fleets, as less efficient vessels remain in the fisheries. In addition, the buyback programs would not work properly without other work opportunities of fishermen who leave the fishery. Second, incentives remain for the remaining vessels to increase their own level of capitalization. Third, even if the buyback programs were effective, the programs would reduce significantly employment in the fisheries and local communities since there is a close relationship between reduction of the number of vessels and fishermen. This will be counter to social policies that may be concerned with protecting societies along remote coastlines (Asche et al., 2008).

After all, legislating for property rights in the fisheries seems necessary in the current situation in Japanese fishing industry primarily. We need to note, however, that the scenario analyses in this study assume that the status-quo fishing activity management system is run by the central planners. Ideally, the efficiencies in fisheries are necessary to be estimated based not only on the current management system run by the central planners, but also other mechanisms such as ITQ. Even with these problems, we believe this paper will provide important implications for policy design in Japan.

References

Asche, F., Eggert, H, Gudmundsson, E., Hoff, A., Pascoe, S., 2008. "Fisher's behavior with individual vessel quotas−over-capacity and potential rent Five case studies." Marine Policy 32, pp.920–927.

Clark, C.W., Munro, G.R., Sumaila, U.R., 2005. "Subsidies, buyback, and sustainable fisheries." Journal of Environmental Economics and Management 50, pp.47–58.

Costello, C., Gaines, S.D., Lynham, J., 2008. "Can catch shares prevent fisheries collapse?" Science 321, pp.1678–1681.

Dervaux, B., Kerstens, K., Leleu, H., 2000. "Remedying excess capacities in French surgery units by industry reallocations: the scope for short and long term improvements in plant capacity utilization." In J. Blank (ed.)., 2000. "Public Provision and Performance: Contribution from Efficiency and Productivity Measurement." Amsterdam: Elsevier, pp.121–146.

Färe, R., Grosskopf, S., Kerstens, K., Kirkley, J., Squires, D., 2001. "Assessing shortrun and medium-run fishing capacity at the industry level and its reallocation." In Johnston, R. S. Shriver, A. L., (eds), "Microbehavior and Macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade." pp.10–14, July 2000, Corvallis, Oregon, USA, Corvallis: International Institute of Fisheries Economics and Trade.

Färe, R., Grosskopf, S., Lovell, C.A.K., 1994. "Production Frontiers." Cambridge: Cambridge University Press.

Färe, R., Grosskopf, S., Kokkelenberg, E.C., 1989. "Measuring Plant Capacity, Utilization and Technical Change: A Nonparametric Approach." International Economic Review 30, pp.655–666.

FAO of the United Nations, 2008a. "FISHERIES MANAGEMENT: 3. Managing fishing capacity." FAO Technical Guidelines for Responsible Fisheries 4(3), FAO/21916/G, (Rome, FAO, 2008a).

FAO of the United Nations, FishStat Plus, Fisheries and Aquaculture Information and Statistics Service, Global Aquaculture Production, 1950–2005 (Rome: FAO, 2008b), http://www.fao.org/fishery/topic/16073 (accessed 8 April 2008).

FAO of the United Nations, 2003. "Measuring capacity in fisheries." In Pascoe, S., Gréboval, D., (eds), FAO FISHERIES TECHNICAL PAPER 445.

Felthoven, R. G., Morrison Paul, C. J., 2004. "Multi-Output, Nonfrontier Primal Measures of Capacity and Capacity Utilization." American Journal of Agricultural Economics 86(3), pp.619–633.

Gordon, H.S., 1954. "The economic theory of a common property resource: the fishery." Journal of political economy 62, pp.124–142.

Grafton, R.Q., Squires, D., Fox, K.J., 2000. "PRIVATE PROPERTY AND ECONOMIC EFFICIENCY: A STUDY OF A COMMON-POOL RESOURCE." The Journal of Law and Economics 43(2), pp.679–713.

Grafton, R.Q., Squires, D., Kirkley, J.E., 1996. "PRIVATE PROPERTY RIGHTS AND CRISES IN WORLD FISHERIES: TURNING THE TIDE?" Contemporary Economic Policy 14(4), pp.90−99.

Holland, D.S., 2007, "Managing environmental impacts of fishing: input controls versus outcome-oriented approaches," International Journal of Global Environmental Issues 72(3), pp.255–272.

Hollan, D.S., Lee, S.T., 2002. "Impacts of random noise and specification on estimates of capacity derived from data envelopment analysis." European Journal of Operational Research 137, pp.10–21.

Holland, D., Gudmundsson, E., Gates, J., 1999. "Do fishing vessel buyback programs work: A survey of the evidence." Marine Policy 23(1), pp.47–69.

Johansen, L., 1968. "Production functions and the concept of capacity." Namur, Recherches Re´centes sur la Fonction de Production, Collection 'Economie Mathe´matique et Econometrie', n8.

Kerstens, K., Vestergaard, N. and Squires, D., 2006. "A Short-Run Johansen Industry Model for Common-Pool Resources: Planning a Fisheries' Industry Capacity to Curb Overfishing." European Review of Agricultural Economics 33(3), pp.361–389.

Kirkley, J.E., Squires, D., Alam, M.F., Ishak, H.O., 2003. "Excess capacity and asymmetric information in developing country fisheries: The Malaysian purse seine fishery." American Journal of Agricultural Economics 85(3), pp.647–662

Kirkley, J.E., Squires, D.E., 1988. "A LIMITED INFORMATION APPROACH FOR DETERMINING CAPITAL STOCK AND INVESTMENT IN A FISHERY." Fishery Bulletin 86(2), pp.339–349.

Macinko, S., Bromley, D.W., 2002. "Who owns America's fisheries? Covello, California: Center for. Resource Economics." Island Press.

Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), 2008. "Japan's Concept of Individual Transferable Quotas." Ministry of Agriculture, Forestry and Fisheries of Japan, Tokyo. < http://www.jfa.maff.go.jp/suisin/yuusiki/dai5kai/siryo_18.pdf >

Morrison, C., 1985. "Primal and dual capacity utilization: An application to productivity measurement in the U.S. automobile industry." Journal of Business and Economic Statistics 3, pp. 312–324.

Nelson, R., 1989. "On the measurement of capacity utilization." Journal of Industrial Economics 37, pp.273–286.

Organisation for Economic Co-operation and Development (OECD), 2006. “Financial Support to Fisheries: Implications for Sustainable Development.” OECD Publishing.

Pasco, S., Gréboval, D., Kirkley, J., Lindebo, E., 2004. “MEASURING AND APPRAISING CAPACITY IN FISHERIES: FRAMEWORK, ANALYTICAL TOOLS AND DATA AGGREGATION.” FAO Fisheries Circular No.994, FIPP/C994(En).

Peters, W., 1985. “Can inefficient public production promote welfare?” Journal of Economics 45, pp.395–407.

Ruddle, K., 1989. “Solving the Common-Property Dilemma: Village Fisheries Rights in Japanese Coastal Waters.” In Berkes, F., (eds), “Common Property Resource: Ecology and Community-Based Sustainable Development. ” London: Belhaven, pp.168–184.

Statistics Department - Ministry of Agriculture, Forestry and Fisheries (MAFF), 2005a. “The 11th (2003) Fisheries Census. ”

Statistics Department - Ministry of Agriculture, Forestry and Fisheries (MAFF), 2005b. “Annual Statistics of Fishery and Fish Culture 2003.”

Statistics Department - Ministry of Agriculture, Forestry and Fisheries (MAFF), 2005c. “Report of Statistical Survey on Fishery Management on 2003.”

Tingley, D., and Pasco, S., 2005. “Factors Affecting Capacity Utilisation in English Channel Fisheries. ” Journal of Agricultural Economics 56 (2), pp.287–305.

Yamamoto, T., 1995. “Development of a Community-Based Fishery Management System in Japan.” Marine Resource Economics 10, pp.21–34.

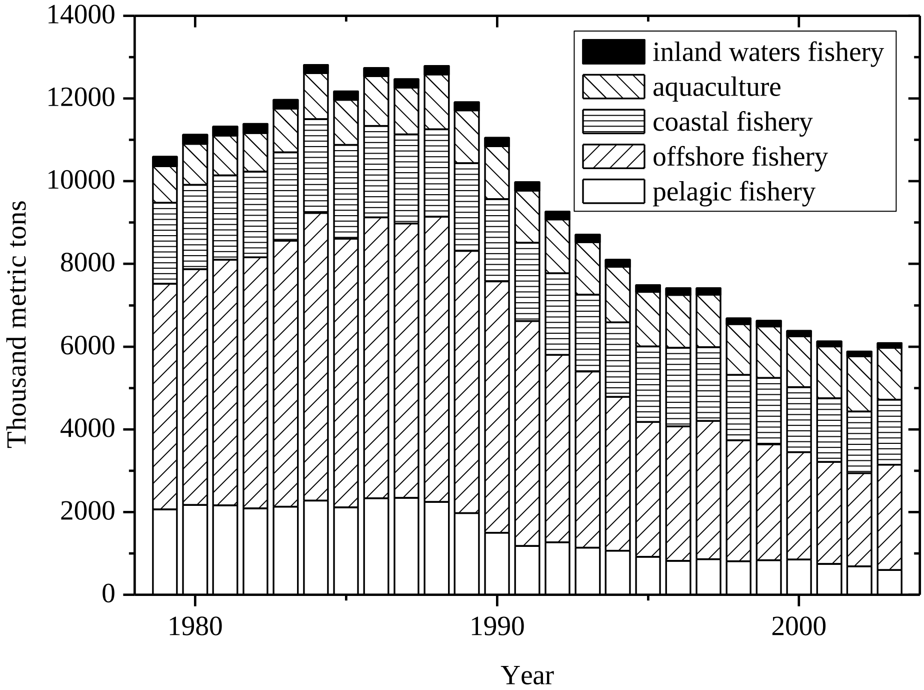


Fig.1 Trend of Fishery Catch in Japan

Source: Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), 2005b, "*Annual Statistics of Fishery and Fish Culture 2003"*

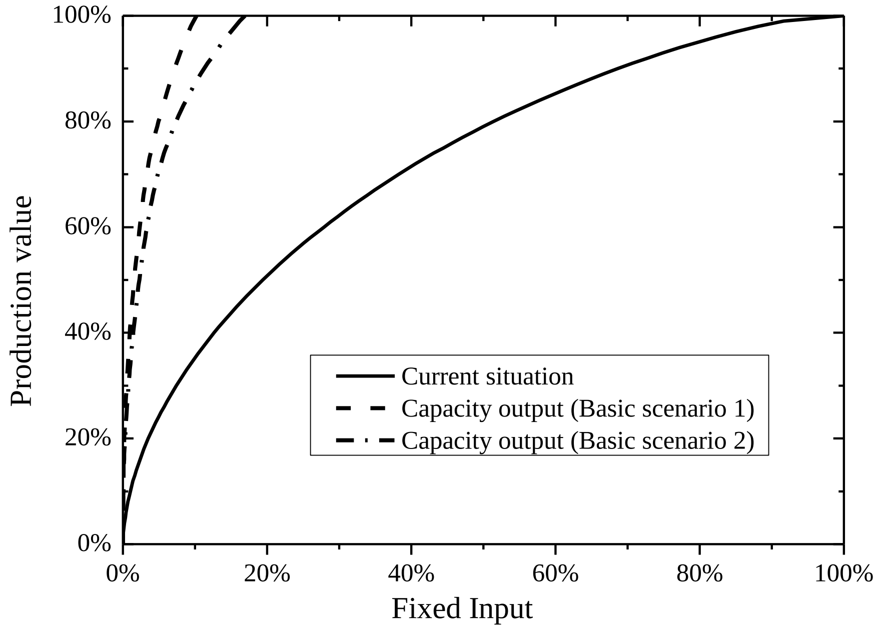


Fig.2. Current and Capacity Output (Catch value)

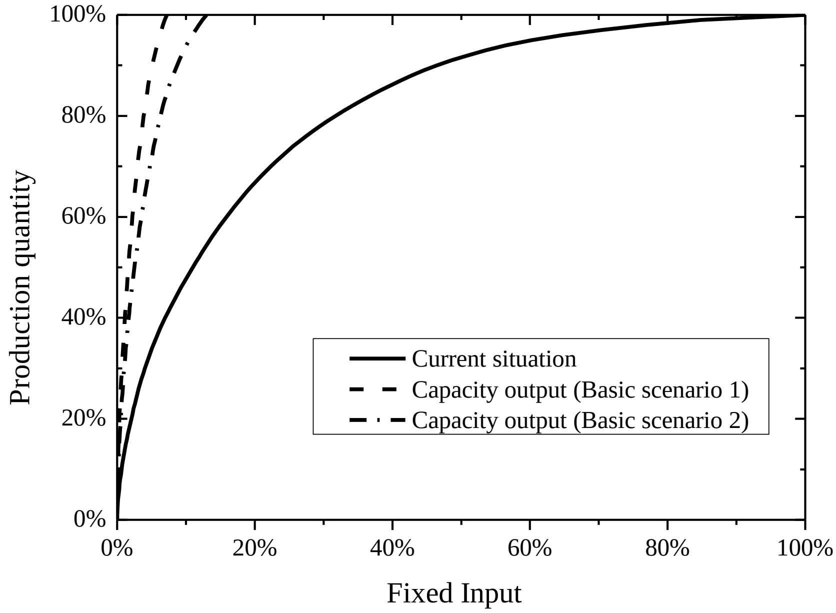


Fig.3. Current and Capacity Output (Catch quantity)

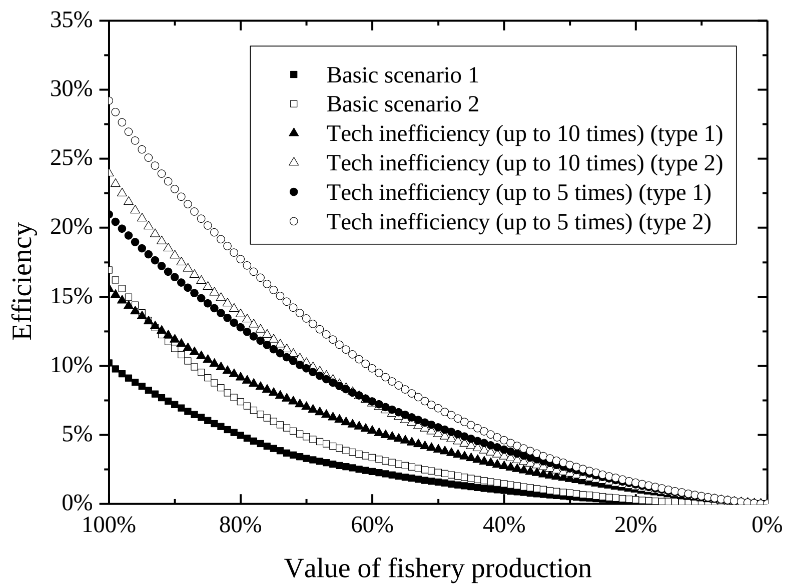


Fig.4. Efficiency Level of Japan’s Fishery:
Catch Value of Output using Industry Model

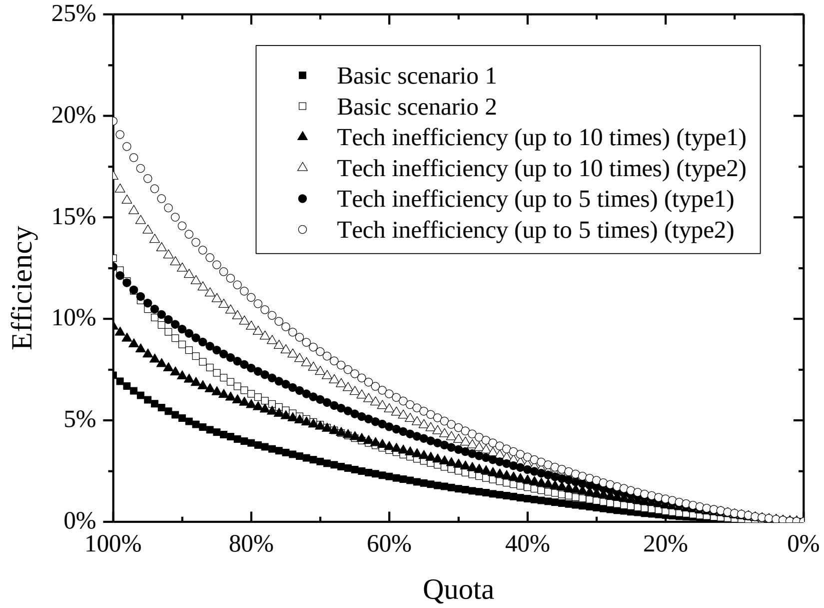


Fig.5. Efficiency Level of Japan's Fishery:

Catch Quantity of Output using Industry Model

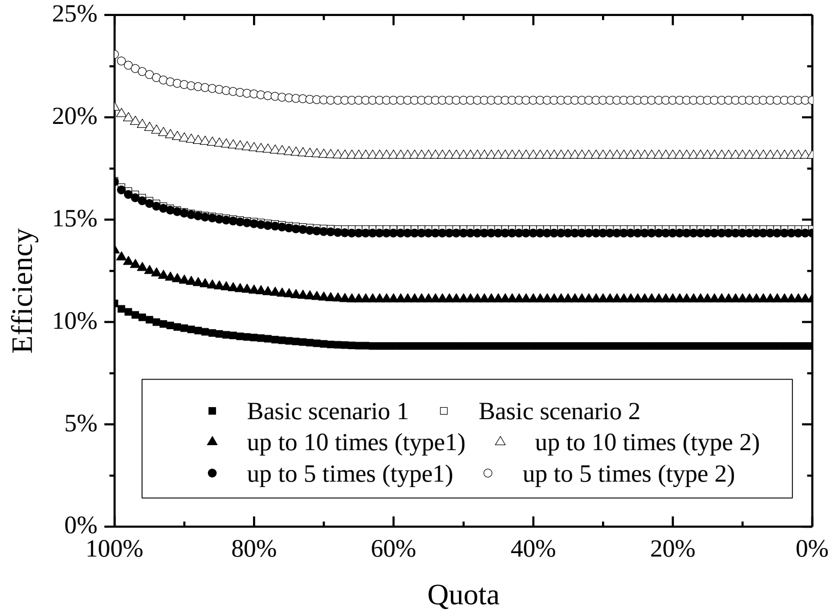


Fig.6. Efficiency Level (Two Outputs Case: TAC and Non-TAC)

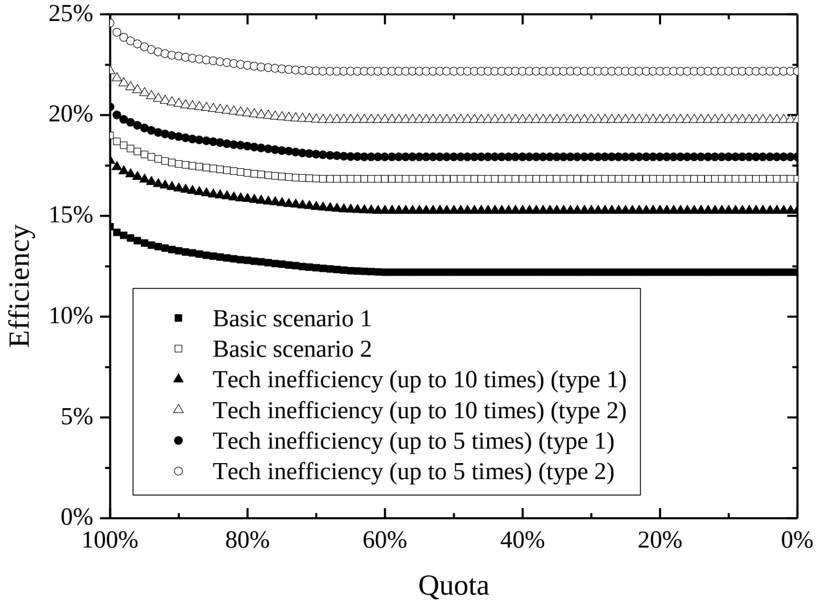


Fig.7. Efficiency Level (Three Outputs Case: TAC and other fish, other marine animals)

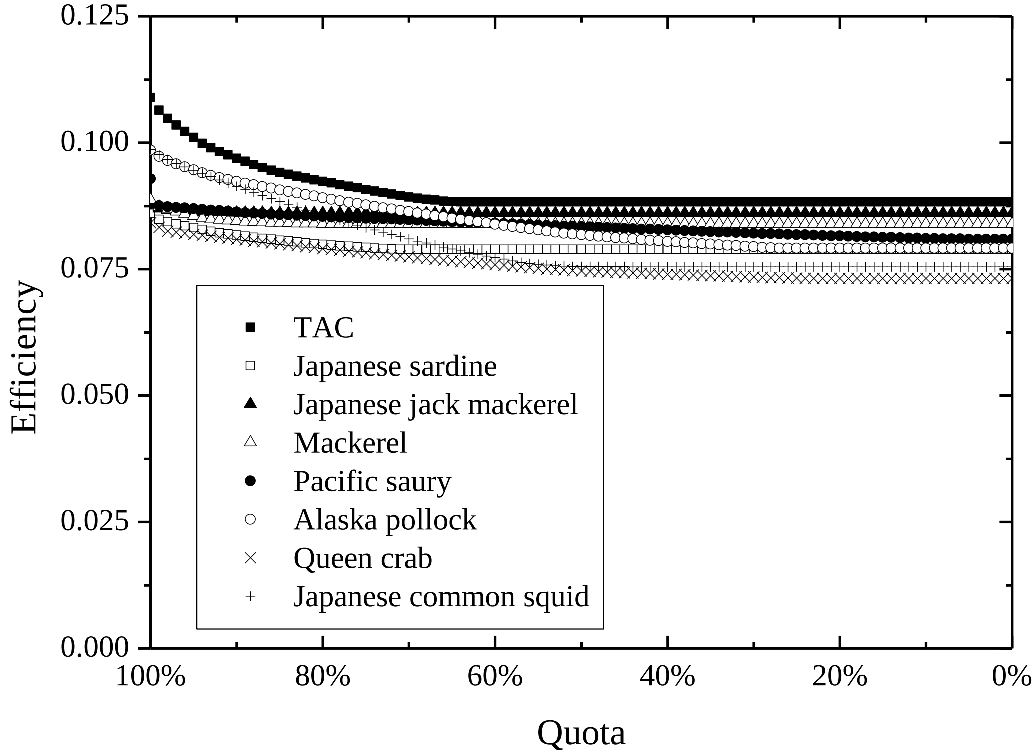


Fig.8. Efficiency Level (Two Outputs Case: Basic scenario 1)

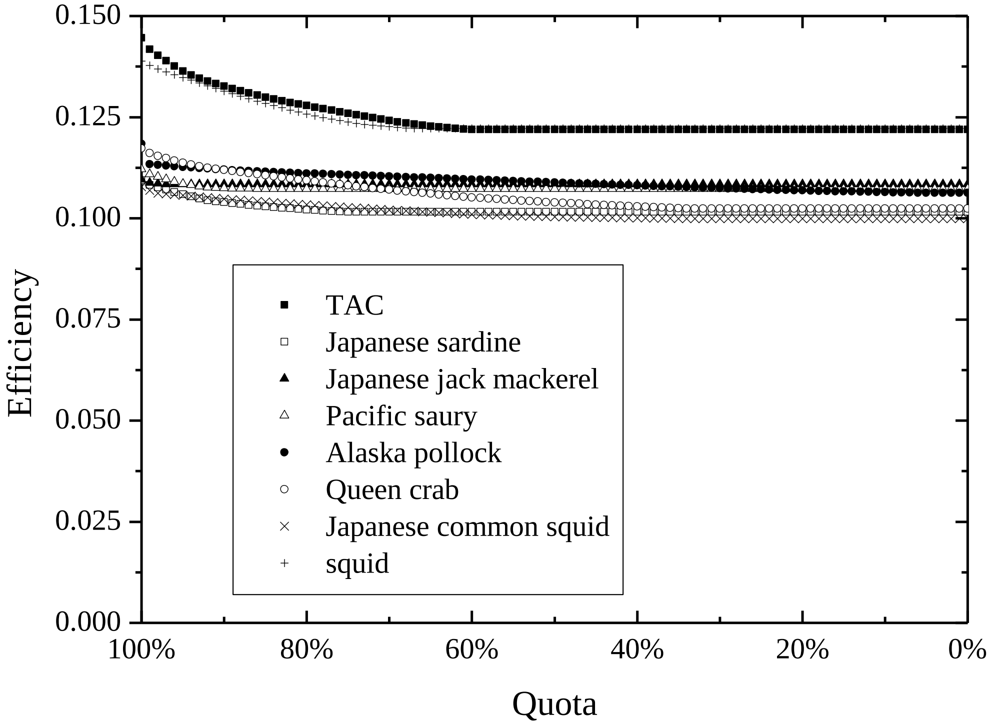


Fig.9. Efficiency Level (Three Outputs Case: Basic scenario 1)

Table 1. Technology (marine fisheries)

Fishery type 1	Large classification	Small classification (39 types of fishery): Fishery type 2
1	Trawls	(1) Distant water trawls, (2) Large trawls in East China sea, Off-shore trawl ((3) one-boat operation, (4) two-boats operation), Small trawl ((5) "Teguri" type 1, (6) other kind of "Teguri", (7) Small sail trawl)
2	Boat seine	(8) Drag net, (9) Pulling net
3	Beach seine	(10) Beach seine
4	Surrounding nets	Large and medium surrounding net ((11) One-boat operation (skipjack and tuna on distant water), (12) One-boat operation (skipjack and tuna on off-shore water), (13) Other than skipjack and tuna, one-boat operation), (14) Two-boats operation, Purse seine ((15) One-boat operation, (16) Two-boats operation, (17) Other surrounding nets)
5	Gill nets	(18) Salmon drift gill net, (19) Billfish drift gill net, (20) Other gill nets
6	Lift nets	(21) Saury stick-held dip net, (22) Other lift nets
7	Fixed net	(23) Large set net, (24) Salmon set net, (25) Small set net
8	Other nets	(26) Other nets
9	Long lines	(27) Tuna long line on distant water, (28) Tuna long line on off-shore water, (29) Tuna long line on coastal water, (30) Other long lines
10	Anglings	(31) Skipjack pole-and-line on district water, (32) Skipjack pole-and-line on off-shore water, (33) Skipjack pole-and-line on coastal water, (34) Squid angling on distant water, (35) Squid angling on off-shore water, (36) Squid angling on coastal water, (37) Mackerel angling, (38) Trolling line fishery, (39) Other anglings

Table 2. Scenario Options

Scenario	Constraints of formulation (17) involved
Basic Scenario 1	$\alpha = 0; 0 \le Q_1 \le 1;$ fishery type 1
Basic Scenario 2	$\alpha = 0; 0 \le Q_1 \le 1;$ fishery type 2
Tolerating technical inefficiency (up to ×10)	$\alpha = 0.1; 0 \le Q_1 \le 1;$ fishery type1 or 2
Tolerating technical inefficiency (up to ×5)	$\alpha = 0.2; 0 \le Q_1 \le 1;$ fishery type1 or 2

Table 3. Estimated marine fishery income and fishery expenditures of the whole fishing industry in Japan in 2003

		Individuals		Firms	Joint management	Fisheries cooperative	Fisheries productive cooperation	Public office	Total	
# of entities		73,868		1,651	2,561	167	111	58	78,416	
Average marine fishing entities										
		Family operation	Employment operation							
Fishery income (million yen)		5.4	69.8	293.6	51.3	unknown	unknown	unknown	unknown	
Fishery expenditures		3.2	71.5	310.5	42.0					
	Wage	0.4	24.6	110.3	15.3					
	Vessels	0.3	1.3	9.2	0.4					
	Fishing gears	0.2	2.0	8.5	1.2					
	Oil	0.5	9.6	42.0	5.1					
	Sale fee	0.3	3.1	11.1	2.5					
	Cost depreciation	0.6	6.0	22.6	1.8					
Fishery profit		2.3	−1.8	−16.9	9.2					
Fishery income		5.4	69.8	293.6	51.3					
Total fishery income (million yen)		480,981.0							1,063,333.1	
Estimated value										
		Family operation	Employment operation							
	Estimated # of entities	72,605	1,263							
Fishery income (million yen)		392,865.7	88,115.3	484,690.7	131,317.8				1,096,989.5	100.0%
Fishery expenditures		229,431.8	90,355.9	512,642.1	107,646.5				940,076.3	85.7%
	Wage	29,042.0	31,121.4	182,138.3	39,134.6				281,436.4	25.7%
	Vessels	22,217.1	1,597.7	15,169.4	1,132.0				40,116.2	3.7%
	Fishing gears	14,956.6	2,577.8	14,028.5	3,139.8				34,702.7	3.2%
	Oil	35,068.2	12,118.4	69,370.1	13,084.1				129,640.9	11.8%
	Sale fee	22,362.3	3,964.5	18,382.2	6,305.2				51,014.3	4.7%
	Cost depreciation	42,546.5	7,610.8	37,306.0	4,604.7				92,068.0	8.4%
Fishery profit		163,433.9	−2,240.6	−27,949.8	23,671.3				156,914.9	14.3%

Notes: The data comes from *the 11th Fishery Census of Japan on 2003* and *Report of Statistical Survey on Fishery Management on 2003*.

Table 4. Simple average Capacity Utilization among aggregated entities per fishery type

						Basic scenario 1				Basic scenario 2			
						Production value		Estimated Production Quantities		Production value		Estimated Production Quantities	
						(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Fishery type1	Fishery type2	Pelagic fishery	Offshore fishery	Coastal fishery	obs	CU_{oo}	CU_{eo}	CU_{oo}	CU_{eo}	CU_{oo}	CU_{eo}	CU_{oo}	CU_{eo}
Total		✓	✓	✓		0.251	0.628	0.230	0.641	0.355	0.660	0.355	0.660
1		✓	✓	✓	898	0.272	0.689	0.238	0.676	0.456	0.731	0.456	0.731
	1	✓			4	0.557	0.629	1.000	1.000	0.579	0.620	1.000	1.000
	2	✓			4	0.254	0.848	0.793	0.793	0.274	0.683	0.793	0.793
	3		✓		66	0.535	0.742	0.707	0.788	0.587	0.766	0.707	0.788
	4		✓		12	0.859	0.933	0.949	0.951	0.508	0.822	0.949	0.951
	5		✓	✓	189	0.354	0.722	0.448	0.709	0.146	0.712	0.448	0.709
	6		✓	✓	614	0.206	0.667	0.413	0.724	0.223	0.654	0.413	0.724
	7		✓	✓	9	0.225	0.750	0.700	0.797	0.141	0.628	0.700	0.797
2			✓	✓	488	0.368	0.694	0.344	0.700	0.441	0.706	0.441	0.706
	8		✓	✓	326	0.348	0.651	0.400	0.681	0.367	0.657	0.400	0.681
	9		✓	✓	162	0.408	0.780	0.522	0.756	0.296	0.786	0.522	0.756
3	10			✓	24	0.763	0.830	0.763	0.830	0.763	0.830	0.763	0.830
4		✓	✓	✓	204	0.387	0.762	0.344	0.750	0.610	0.778	0.610	0.778
	11	✓			8	0.888	0.923	1.000	1.000	0.688	0.874	1.000	1.000
	12		✓		3	0.893	0.982	0.934	1.000	0.397	0.929	0.934	1.000
	13		✓		25	0.657	0.820	0.737	0.802	0.691	0.836	0.737	0.802
	14		✓		4	0.603	0.916	1.000	1.000	0.906	0.942	1.000	1.000
	15		✓	✓	98	0.307	0.779	0.526	0.752	0.236	0.761	0.526	0.752
	16		✓	✓	29	0.331	0.721	0.603	0.781	0.333	0.684	0.603	0.781
	17		✓	✓	37	0.290	0.640	0.603	0.739	0.262	0.650	0.603	0.739
5			✓	✓	1546	0.236	0.649	0.234	0.654	0.245	0.623	0.245	0.623
	18		✓	✓	10	0.365	0.637	0.532	0.601	0.248	0.689	0.532	0.601
	19		✓	✓	11	0.614	0.796	0.993	0.993	0.647	0.840	0.993	0.993
	20		✓	✓	1525	0.233	0.648	0.237	0.620	0.231	0.653	0.237	0.620
6			✓	✓	176	0.542	0.744	0.511	0.736	0.593	0.766	0.593	0.766
	21		✓	✓	50	0.672	0.814	0.693	0.833	0.682	0.822	0.693	0.833
	22		✓	✓	126	0.490	0.717	0.553	0.740	0.443	0.702	0.553	0.740
7				✓	1145	0.226	0.602	0.221	0.600	0.339	0.655	0.339	0.655
	23			✓	300	0.331	0.750	0.380	0.692	0.328	0.749	0.380	0.692
	24			✓	82	0.254	0.506	0.295	0.504	0.256	0.506	0.295	0.504
	25			✓	763	0.182	0.554	0.328	0.657	0.175	0.552	0.328	0.657

8	26		✓	✓	96	0.433	0.636	0.433	0.636	0.433	0.636	0.433	0.636
9		✓	✓	✓	707	0.374	0.730	0.364	0.741	0.473	0.722	0.473	0.722
	27	✓			59	0.474	0.821	0.684	0.801	0.401	0.821	0.684	0.801
	28		✓		68	0.644	0.883	0.733	0.892	0.684	0.890	0.733	0.892
	29		✓	✓	60	0.420	0.716	0.602	0.716	0.394	0.746	0.602	0.716
	30		✓	✓	520	0.322	0.701	0.399	0.692	0.315	0.712	0.399	0.692
10		✓	✓	✓	2199	0.150	0.529	0.113	0.572	0.292	0.611	0.292	0.611
	31	✓			18	0.715	0.894	0.799	0.802	0.749	0.885	0.799	0.802
	32		✓		17	0.701	0.885	0.853	0.876	0.664	0.869	0.853	0.876
	33		✓	✓	36	0.227	0.500	0.625	0.827	0.210	0.565	0.625	0.827
	34	✓			7	0.624	0.811	0.995	1.000	0.674	0.785	0.995	1.000
	35		✓		27	0.346	0.589	0.723	0.812	0.379	0.626	0.723	0.812
	36		✓	✓	493	0.208	0.484	0.270	0.486	0.188	0.521	0.270	0.486
	37		✓	✓	16	0.085	0.435	0.726	0.769	0.085	0.477	0.726	0.769
	38		✓	✓	310	0.118	0.406	0.287	0.492	0.106	0.450	0.287	0.492
	39		✓	✓	1275	0.111	0.566	0.259	0.667	0.059	0.613	0.259	0.667

Table 5. Computed Fishery Expenditures of Each Scenario

	Costs Vessels & Fishing gears (θ)	Oil $\left(\frac{\sum w_j^2 \cdot x_{j,f,2}^* \cdot x_{j,v,1}^*}{X_{f,1} \cdot X_{v,1}}\right)$	Wages $\left(\frac{\sum w_j^2 \cdot x_{j,v,1}^* \cdot x_{j,v,2}^*}{X_{v,1} \cdot X_{v,2}}\right)$	Total
Current situation (unit: billions of yen)	63.5	110.2	239.2	412.9
1 output; Production value				
Basic scenario 1 (10 fishing types)	10.21%	11.99%	35.26%	25.20%
Technical inefficiency (up to ×10)	15.57%	18.72%	45.43%	33.71%
Technical inefficiency (up to ×5)	20.96%	25.15%	53.65%	41.02%
Basic scenario 2 (39 fishing types)	16.93%	19.31%	44.14%	33.33%
Technical inefficiency (up to ×10)	23.93%	25.16%	50.82%	39.83%
Technical inefficiency (up to ×5)	29.21%	32.96%	61.49%	48.90%
1 output; Production quantity				
Basic scenario 1 (10 fishing types)	7.21%	8.30%	28.78%	20.00%
Technical inefficiency (up to ×10)	9.62%	11.62%	27.51%	20.52%
Technical inefficiency (up to ×5)	12.55%	10.79%	31.81%	23.24%
Basic scenario 2 (39 fishing types)	12.99%	14.64%	35.64%	26.55%
Technical inefficiency (up to ×10)	17.00%	19.20%	40.87%	31.41%
Technical inefficiency (up to ×5)	19.74%	22.05%	44.24%	34.55%
2 outputs; TAC and other species				
Basic scenario 1 (10 fishing types)	10.90%	12.73%	36.54%	26.24%
Technical inefficiency (up to ×10)	13.50%	16.20%	39.98%	29.56%
Technical inefficiency (up to ×5)	16.84%	20.19%	44.78%	33.92%
Basic scenario 2 (39 fishing types)	16.89%	19.77%	42.99%	32.78%
Technical inefficiency (up to ×10)	20.47%	23.51%	47.88%	37.16%
Technical inefficiency (up to ×5)	23.07%	25.98%	51.10%	40.08%
2 outputs; Each species and other species				
Japanese sardine	8.60%	9.60%	26.24%	19.09%
Japanese jack mackerel	8.77%	10.17%	30.58%	21.78%
Mackerel	8.87%	10.26%	28.89%	20.84%
Pacific saury	9.29%	11.13%	37.32%	26.02%
Alaska Pollock	9.85%	11.24%	35.95%	25.34%
Queen crab	8.42%	9.48%	30.45%	21.46%
Japanese Common Squid	9.87%	11.56%	29.49%	21.69%
3 outputs; TAC, other fish and other marine animals				
Basic scenario 1 (10 fishing types)	14.46%	16.75%	44.17%	32.28%
Technical inefficiency (up to ×10)	17.72%	20.62%	46.94%	35.42%
Technical inefficiency (up to ×5)	20.39%	23.75%	49.77%	38.30%
Basic scenario 2 (39 fishing types)	18.99%	22.05%	46.28%	35.61%
Technical inefficiency (up to ×10)	22.19%	25.37%	51.08%	39.77%
Technical inefficiency (up to ×5)	24.56%	27.60%	53.59%	42.18%
3 outputs; Each species, other fish and other marine animals				
Japanese sardine	10.94%	12.29%	31.36%	23.13%
Japanese jack mackerel	10.96%	12.58%	35.48%	25.59%
Mackerel	11.21%	12.75%	33.78%	24.69%
Pacific saury	11.84%	13.90%	40.44%	28.96%
Alaska Pollock	11.72%	13.25%	38.13%	27.43%
Queen crab	10.78%	12.11%	32.25%	23.57%
Japanese Common Squid	13.88%	15.82%	40.58%	29.86%

Natural Resource-Based Economies and Rural Sustainability*

Shun'ich Teranishi,[1] Toshikazu Yamakawa,[2] Takeshi Fujiya[3] and Kouhei Fujii[4]

[1] Graduate School of Economics, Hitotsubashi University
[2] Graduate School of Economics, Hitotsubashi University
[3] Graduate School of Economics, Hitotsubashi University
[4] Graduate School of Art and Sciences, The University of Tokyo

Abstract

In FY2009 we launched a new research and education project at Hitotsubashi University on "natural resource-based economies (NREs)," sponsored by the Norinchukin Bank. The project is called "Policy Research for Sustainable Development of Natural Resource-based Industries and Communities." In the project we propose to understand so-called "primary industries" such as agriculture, as well as rural communities, which are mainly dependent on the "primary industries." These are the most important NREs. They are in turn supported by various kinds of natural ecosystem services.

Using the above theoretical framework of the NER concept, this article examines three basic issues: 1) policy priority for agriculture and rural communities, 2) agricultural land use and management of rural resources, and 3) human resources and capacity-building for agriculture and rural communities. These are used in focusing on Japan's recent situation in hopes of securing rural sustainability in the 21st century.

Key Words:
1) Natural resource-based economy, 2) agriculture, 3) rural community, 4) multiple functions, 5) sustainability

*This paper will be presented at the first Congress of the East Asian Association on Environment and Natural Resource Economics（EAAENRE）, August 18-19, 2010, Hokkaido University， Sapporo, Japan

I. Introduction

As the globalization of the market economy proceeds, a worldwide trend that includes Japan and other Asian countries is the progressive weakening of agriculture, forestry, and fisheries (the so-called primary industries), and the communities that rely on those industries. As such, there is a growing need for integrated policy studies which take a fresh look at the significance and place of the natural resource-based industries of agriculture, forestry, and fisheries, examine how we should envision the sustainable development of communities which depend on those industries, formulate a new philosophy and a vision for them, and try to achieve them.

Based on this fundamental awareness, and with a donation from The Norinchukin Bank, a Hitotsubashi University group launched a unique research and education project in FY2009 called "natural resource-based economies." This project's name and primary purpose are "Policy Research for Sustainable Development of Natural Resource-Based Industries and Communities," and it will conduct special lectures (including, for example, public lectures and symposia) which make use of project results.[1]

For this collection of papers on "rural sustainability," in this paper we would like to explore somewhat the contemporary challenges in working toward the sustainable development especially of agriculture and rural communities, based on our efforts under the above-described project.

II. Natural Resource-Based Economies and the Sustainability of Agriculture and Rural Communities

The key word "natural resource-based economy" (NRE) used in the project was coined by our group representative Shun'ichi Teranishi, and is defined as "an economy which is based on natural resources[2] and is made viable by them."

---

[1] See the Hitotsubashi University website "Natural Resource-Based Economies" for an overview of this project (<http://www2.econ.hit-u.ac.jp/~kankyoprj/ssk/>, in Japanese).

[2] "Natural resources" are conceived as not just those in the narrow sense, but as "natural environment resources" in the broad sense including the atmosphere, water, soil, wildlife, and other wild natural ecosystems and secondary nature. On

Needless to say, natural resources are essential to the economic functioning of human societies, and natural ecosystems underpin those resources. To put it another way, our daily lives are made economically viable by receiving a variety of ecosystem services[3] from natural ecosystems, and by the repeated use of resources (resource cycling) in which we extract natural resources, produce/distribute/consume them so as to make them useful for human livelihoods, and then discard/dispose of the final wastes into natural ecosystems. Such economic activity has continued to the present day through the long history of humankind. In short, NREs are the original economic activity of human society, which is built on natural ecosystems and made possible by receiving ecosystem services obtained from those ecosystems, and by using and cycling natural resources. As the sustainability of NREs is now jeopardized, we face the challenge of how to ensure it.

Incidentally, agriculture and rural communities have formed the basis of these NREs and play very important roles in them. As many people know, it is said that humankind started agriculture about 15,000 years ago, and that practice wrought landmark changes in the nature of human societies, which until then had been based primarily on hunting, gathering, and fishing for several million years prior to agriculture.

First, livelihoods based on hunting, gathering, and fishing assume wild natural ecosystems to be a given, and did not greatly alter them, but livelihoods based on agriculture involve conscious human influence on natural ecosystems, and through that, the artificial alteration of those ecosystems. As these alterations accumulated throughout history, they resulted in unique agricultural ecosystems based on interactions between humans and nature, while at the same time being based on wild natural ecosystems. In contrast to wild nature, these agricultural ecosystems had a significance and role as secondary nature, nurtured biodiversity that is richer that of wild natural ecosystems, and contributed to their maintenance and conservation.[4]

---

this point see R. David Simpson, Michael A. Toman, and Robert U. Ayres, ed. (2005), *Scarcity and Growth Revisited: Natural Resources and the Environment in the New Millennium*.

[3] On the concept and significance of ecosystem services, see the Millennium Ecosystem Assessment (2005). See also the work of Gretchen Daily (1997), who played a leading role in the assessment.

[4] On the relationship between agricultural ecosystems and biodiversity, see Satoshi

Second, livelihoods based on agriculture formed rural communities, which are unique local communities, as "social venues where agriculture is practiced"[5] because populations take up permanent residence in certain areas. Such local communities developed traditions and cultures peculiar to each rural communities and became crucial platforms for the historical accumulation of those traditions and cultures, and their continuity and development across generations.

Therefore if we view this from a human-history perspective, we could say that agriculture and rural societies originally not only functioned as production bases for food and other things essential for human livelihood, or as supply bases for raw materials and other things needed for industrial production, but also had diverse meanings and roles that included natural, economic, social, and cultural facets (what are called "multiple functions").

But especially since the second half of the 20th century, Japan and other countries have undergone the transformation to the market economy and rapid-growth industrial society, and now we are in the first half of the 21st century, when the diverse meanings and roles that have been maintained by agriculture and rural societies over many years are rapidly weakening, and even the continued existence of agriculture and rural societies is increasingly endangered in Japan, other Asian countries, and indeed throughout the world. This is the basic context in which "rural sustainability" is addressed as a crucially important theme in this collection of papers.

What must be done to overcome the present crisis endangering the continuation of agriculture and rural society, and to ensure rural sustainability? The following sections consider three basic problems (basic issues) which seem to be especially important, while focusing on the state of agriculture and rural society in Japan.

III. Agriculture and Rural Communities in Political Policy

The first problem requiring discussion is what to give agriculture and rural society in modern political policy. In other words, from the perspective of assuring rural sustainability, how must one see the place of agriculture and rural

---

Osawa, Satoru Okubo, Yoshinobu Kusumoto, and Takuya Mineta (2008).

[5] See Hirobumi Uzawa (2001) on the concept of "social common capital," which conceives rural societies as "social venues where agriculture is practiced" and finds in them a unique reason for being. See Teranishi (2001) for a review of that book.

communities in terms of political policy?

In response to the "New Direction in Policy on Food, Agriculture, and Rural Areas" (known as the "New Policy") that Japan developed in 1992, the government enacted the "Basic Law on Food, Agriculture, and Rural Areas" ("New Basic Law") in July 1999 to replace the former Basic Agriculture Law of 1961. The New Basic Law set forth four fundamental principles on the policy placement of agriculture and rural society: (1) ensuring a stable food supply, (2) discharging multiple functions,[6] (3) sustainable development of agriculture, and (4) economic development of rural areas. Pursuant to the New Basic Law, the Cabinet approved the "Basic Plan on Food, Agriculture, and Rural Areas" (below, "Basic Plan") in March 2000, and an updated Basic Plan in March 2007. Under this Basic Plan, a system of "policy measures to be implemented in an integrated and planned manner" are arranged into three major categories: (1) "measures for ensuring a stable food supply" (including raising the food self-sufficiency rate), (2) "measures for the sustainable development of agriculture" (such as creating a desirable agricultural structure), and (3) "measures for the economic development of rural areas" (such as conserving and managing local resources).[7]

As noted previously, agriculture and rural societies have always had diverse meanings and roles, and in recent years one could say that, in Japan too, this fact has more or less been given a place in the government's system of policy measures. But the questions here are: To what extent have these actually been given sufficient policy placement? And what provisions have been made to ensure they are systematic and consistent in terms of policy? A full-blown discussion of these points requires an integrated analysis and assessment of fiscal provisions to guarantee the effectiveness of those policy measures, the concrete mechanism of those measures, and of the measures' actual policy effectiveness. As a specific example, here we shall

---

6 The New Basic Law states in Article 3, "The manifold functions (below, "multiple functions") other than the function of supplying food and other agricultural products, which arise through the conduct of agricultural production activities in rural areas, such as conserving land, recharging aquifers, conserving the natural environment, shaping fine landscapes, and passing on culture to future generations, must be properly and fully discharged now and in the future in view of the role they play in stabilizing the people's livelihoods and the national economy."

7 See "The Newest Basic Plan on Food, Agriculture, and Rural Areas" Editorial Committee (2006).

discuss the "System for Direct Payments to Hilly and Mountainous Areas," which was launched in FY2000 as an important measure relating to the "multiple functions" that were given a place among the fundamental principles in the New Basic Law.

As is well known among people familiar with the matter, this program directly pays subsidies of certain amounts (such as ¥21,000 for rice paddies or ¥11,500 for upland fields per 10 ares) from the perspective of ensuring "multiple functions" while maintaining agricultural production in hilly and mountainous areas, which are at a disadvantage to plains in terms of agricultural production, for farm production continued at least five years pursuant to agreements with villages or individuals on farmland with disadvantageous conditions, such as steeply or gently sloped land, or small or irregularly shaped plots, as locally designated[8] by regional economic development legislation or other provisions.[9] According to the *2009 Food, Agriculture and Rural Areas White Paper*, as of FY2007, 28,708 agreements had been signed, and subsidies had been paid on 665,000 ha of farmland, accounting for 80% of that eligible.[10]

---

[8] Areas designated under the "Law Concerning the Promotion of the Improvement of Basic Conditions of Agriculture, Forestry and Other Business in Hilly and Mountainous Areas" (Agriculture and Forestry Improvement Law), "Law for the Economic Development of Mountain Villages," "Law for Special Measures for Promoting the Development of Depopulated Areas" (Depopulated Areas Law), Law for Economic Development of Peninsulas," "Law for Economic Development of Isolated Islands," "Special Measures Law for the Economic Development of Okinawa," "Special Measures Law for Development of the Amami Islands," and "Special Measures Law for the Economic Development of the Ogasawara Islands," as well as areas designated by prefectural governors.

[9] In FY2005, based upon the state of implementation to date, the transition to "Second-Phase Measures" was made to facilitate the development of village master plans, fostering of sustainers, reinforcing of inter-village collaboration, and other initiatives.

[10] See: Ministry of Agriculture, Forestry and Fisheries (2009). According to the *2009 Implementation of Direct Payment Program in Hilly and Mountainous Areas (Forecast)* by the Rural Development Bureau, Rural Policy Department, Hilly and Mountainous Areas Development Division, Hilly and Mountainous Areas Development Promotion Office, later figures are: 28,767 agreements signed (10

Incidentally, let's check the extent of the fiscal provisions for paying out the above subsidies. In terms of the FY2008 budget, it was about ¥22.1 billion, which is about 1% of the total agriculture-related general budget of that year. Are the fiscal provisions and budget size for these subsidy payments appropriate and sufficient? On this point, the basic assessment will perhaps differ from one person to another depending on how one sees the program's policy placement.

The "Intermediate Assessment" (released in June 2008)[11] of the "Second-Phase Measures" started in 2005 and implemented by the Ministry of Agriculture, Forestry and Fisheries (MAFF) in 2007 shows that of the more than 28,000 agreements up for assessment, 95% were rated either "excellent" or "good,"and that 97% of the municipalities in which subsidies had been paid said that the money had vitalized them or otherwise helped. The "Final Assessment" (released in August 2009)[12] was roughly the same. Indeed, in the hilly and mountainous areas that received fixed-amount subsidies pursuant to village agreements, one can discern the real effect of policies in that farm production is being maintained and continued in some form on land that is hard to farm. In this respect, one could perhaps say that the fixed-amount subsidy payments under this program have had an important "incentive effect" on the maintenance and continuation of farm production in the target areas.

But village agreements have not been made for 20% of the farmland (nearly 10,000 villages) that could be covered by the program. How should this fact be regarded? It means that there are quite a few areas whose populations have declined and aged, and whose village functions are so extremely weakened that it is even difficult for them to be helped by this program. It is thought that in such areas ensuring "multiple functions " through the maintenance and continuation of agricultural production now faces a critical difficulties. Assuming that the fiscal measure of paying subsidies under the System for Direct Payments to Hilly and Mountainous Areas is supposed to function effectively to ensure "multiple functions " in such crisis-stricken locales, then perhaps one can pass harsh judgment on the program by concluding that it is of no help in the most important places, and that the problems of hilly and mountainous areas will continue

---

more than previous year) and subsidies paid on 664,000 ha (719 ha fewer than the previous year).

[11] See Ministry of Agriculture, Forestry and Fisheries (2008).

[12] See Ministry of Agriculture, Forestry and Fisheries (2009).

worsening.[13]

And if this is considered in terms of economic theory, it is perhaps possible to examine a different policy positioning that is somewhat more in-depth. In other words, the fiscal provision for subsidy payments is more positively seen as a national payment of compensation for the social benefits provided by the "multiple functions " of Japan's hilly and mountainous areas. Assuming a basis in such policy positioning, the above-mentioned budget of about ¥22.1 billion annually is a mere cosmetic solution, and therefore future consideration of a bolder expansion would make sense.

In fact, Japan's hilly and mountainous areas account for about 70% of Japan's total land area, about 40% of farming families and amount of farmland cultivated, and, even in terms of the value of agricultural produce sold, they account for about 30%. What is more, almost all of them are located upstream from urban areas and lowland farming areas. In view of these facts, it is no exaggeration to say that nearly all Japanese in some way benefit from the multiple functions of hilly and mountainous areas. In this connection, a report submitted in November 2001 by the Science Council of Japan gave an estimate of ¥8,222,600,000,000 (annually) as the total "monetary assessment of agriculture's multiple functions,"[14] most of which

---

[13] See Motoyuki Goda, ed. (2001) and Yoichi Yamaura (2009).

[14] Breakdown: (1) Flood-prevention function, ¥3,498,800,000,000 (replacement cost method used to assess flood-control dams as substitutes), (2) river flow regime stabilization function, ¥1,463,300,000,000 (replacement cost method used to assess water-utilization dams as substitutes), (3) aquifer recharge function, ¥53,700,000,000 (direct method used to assess price difference between tap water fees and groundwater), (4) soil erosion (runoff)-prevention function, ¥331,800,000,000 (replacement cost method used to assess erosion-prevention dams as substitutes), (5) landslide-prevention function, ¥478,200,000,000 (replacement cost method used for assessment of monetary amount of damage prevented by cultivation), (6) organic waste disposal function, ¥12,300,000,000 (replacement cost method used to assess landfill sites as substitutes), (7) climate-mitigation function, ¥8,700,000,000 (direct method used for assessment from amount of space cooling cost saved), and (8) recreation and relaxation function, ¥2,375,800,000,000 (travel cost method used for assessment from amount of household expenditures on travel and the like by urban households). Of course, these estimates are just one way of calculating benefits. Nevertheless, it is significant that they are from a report by the

are sustained by hilly and mountainous areas.

Further, if one includes in the importance of biodiversity conservation the assessments of social benefits from "ecosystem services,"[15] which have started garnering attention in recent years against the backdrop of the heightened awareness around the world, the multiple functions of Japan's hilly and mountainous areas have very great significance and roles. Depending on what placement one sees for this in political policy, and by extension, depending on how one conceives the placement of and the basic vision for Japan's future agriculture and rural society, it will perhaps be necessary to once again consider, in a forward-looking manner, what kind of program Japan's System for Direct Payments to Hilly and Mountainous Areas should be.[16]

IV. Land Use and Resource Management in Agriculture and Rural Communities

The second problem requiring discussion is land use and resource management in agriculture and rural communities. This too is a basic, unavoidable challenge if we are to ensure rural sustainability.

Starting with land use, the amount of arable land in Japan peaked at 6,090,000 ha in 1961, and has steadily decreased since then, standing at 4,628,000 ha in 2008. Mainly responsible for this decline in farmland are abandonment and conversion to other uses such as residential land. In 2008 those two causes accounted for 41% and 39%, respectively. In particular, the amount of farmland abandoned has been increasing since 1985, and rose to 386,000 ha in 2005. Additionally, the farmland utilization rate (the aggregate planted area as a percentage of total farmland) tends to decrease year by year, standing at 92.6% in 2007. It was under these circumstances that MAFF developed the "Farmland Reform Plan" in December

---

Science Council of Japan, a third-party organization of experts.

[15] In this respect, the development of indicators for quantitatively assessing ecosystem services and the consideration of methods for their economic assessment have been important challenges during recent years.

[16] In this respect, there is a need to focus on new trends seen in policy positioning and program design in the "direct subsidy payments" and "environmental payments" under the EU's Common Agricultural Policy (CAP), which Japan drew on for the System for Direct Payments to Hilly and Mountainous Areas. See Mikitaro Shobayashi (2009).

2008. As part of that plan, the ministry took an approach which redesigns the basis of the farmland system from "ownership" to "use," and it is working on changes that include making it more difficult to convert farmland to other uses, securing farmland within agricultural land zones, clarifying responsibilities of people having farmland rights, facilitating farmland consolidation, finding and increasing people to use farmland, and beefing up measures to deal with farmland abandonment.[17]

Needless to say, it is desirable that land use in agriculture and rural societies prevent the chaotic conversion of farmland to other uses, and expedite farmland consolidation into management entities that use farmland more appropriately and efficiently, while at the same time keeping farmland from being abandoned. But experts point out that, in view of the actual situation, restrictions on farmland conversion under the Agricultural Land Act are not necessarily functioning effectively, and that zoning restrictions under the Act Concerning Establishment of Agricultural Promotion Areas is afflicted with various problems.[18] Although in recent years the amount of farmland converted to other uses has tended to decline, the data for 2007 show that of the 16,183 ha converted, 33% became parking lots, material storage yards, quarrying land, and sites used for the operations of agriculture, forestry, and fishing facilities, while 31% became residential land. Farmland conversion by exclusion from agricultural zones accounted for 15.7%. In nearly all cases, such farmland conversion brings about disorderly sprawl in the land use of rural societies, and also leads to the ruin of harmonious and beautiful rural landscapes. This signifies the loss of the value of rural societies itself, which should be seen as a vital environmental-quality asset. In this respect, therefore, it is a vital task to develop local plans on the basic municipal level to maintain or create conservation-oriented and rational land use systems that include rural landscapes, and to expedite institutional reforms that will enable effective regulation and inducements based on those plans.

In that connection, the March 2007 "Basic Plan" clearly states, with regard to "Creating Good Rural Landscapes" that "[local governments] shall, while providing for consensus-building among local citizens and collaboration with city dwellers and other parties, encourage planned land use such as inducing the building of facilities that take landscapes into consideration, and agricultural land use harmonized with landscapes through the development of Rural Landscape

---

[17] Ibid., note 10, p. 80.

[18] See Daisuke Takahashi (2009).

Agricultural Promotion Area Development Plans, thereby providing for the appropriate conservation of farmland.[19] There is a pressing need to consider specific means that can guarantee the plan's effectiveness.

In connection with resource management in agriculture and rural societies, another critical matter that needs consideration is the desirable form of maintenance and conservation practiced by joint management systems for not only farmland, but also rural-area resources including agricultural water supply facilities such as irrigation water and irrigation reservoirs, commons including grasslands and forests, and mixed forests. In particular, there is a trend in which the traditional and customary organizations and institutions, or their practitioners, which have sustained the joint management systems for rural-area resources, are quickly disappearing or weakening, and society is faced with the very difficult problem of what we should do amid this trend to build new management systems and management entities. It is not easy to set forth a convincing proposal for a solution in this paper. One idea might be to envision trust-type[20] management systems based on nonprofit organizations (NPOs), citizen organizations, or other organizations that understand well the inherent value with respect to certain rural-area resources (such as mixed forests), and have a strong will and desire to make voluntary commitments to their maintenance and conservation. But the reality is actually quite complex, thereby allowing for no one-size-fits-all solution. One fortunate development is that in recent years there has been much research in Japan and abroad on the commons.[21] Instead of thinking about such problems surrounding land use and resource management along the same lines as conventional policy, it will be important to take a fundamentally different approach to the conservation and management of natural resources, and the relationship with the significance and roles of agriculture and rural areas, and, while drawing on new research of recent years and on good practical examples from Japan and other countries, go full throttle on theoretical and practical exploration. This matter is closely related to the problem of the sustainers of agriculture and rural societies discussed in the following section.

---

[19] Ibid., note 7, p. 172.

[20] On the principles and significance of trust-type rural-area resource management, see Shun'ichi Teranishi (2005a), Shun'ichi Teranishi (2005b), and Takeshi Fujiya (2008).

[21] See Takeshi Murota, ed. (2009).

V. Sustainers of Agriculture and Rural Communities

The third and last problem is that of the sustainers of agriculture and rural commuinities, which is the most pressing and crucial issue to the challenge of ensuring rural sustainability.

It is widely known that Japan has entered population decline, and its population is rapidly aging. It is under these circumstances that especially the core farmers who basically sustain agriculture and rural communities are decreasing and aging at alarming rates. In 2008 there were 1,970,000 (of which 60% were 65 or older), finally falling below the 2 million mark. That is a decline of about 20% from a decade earlier (1998). As Odagiri (2009)[22] observes with a strong sense of crisis, now progressing in Japanese agriculture and rural communities amid this trend are "population hollowing" (from social decrease to natural decrease), "land hollowing" (farmland and forest degradation), "village hollowing" (weakening of village functions), and "pride hollowing" (loss of meaning and pride by inhabitants to keep living there). In the early 1990s the term "marginal village"[23] appeared in Japan, and there are real concerns that from now on there could be many "disappearing villages."

Against this backdrop, in recent years MAFF has endeavored to foster and secure new people to sustain agriculture and rural societies through initiatives that include training certified farmers, organizing village farming operations, and encouraging people to start farming by renting farmland for agricultural production corporations and other general corporations. Some results of these initiatives are 239,286 operations run by certified farmers (as of March 2008), 13,436 operations run at the village level (as of February 2009), and 10,519 agricultural production corporations (as of 2008). In view of the seriousness of the situation, however, this is nowhere near a solution.

Deserving some attention are the gradual increases in the young people employed by agricultural production corporations and in people from non-farming families who take up farming in recent years. There are rising expectations that these supply vital channels for young people to take up farming. For example, in 2007 there were 73,460 new farmers, of which 7,290 were hired by agricultural

---

22 See Tokumi Odagiri (2009).

23 See Akira Ohno (2005).

production corporations and other entities (a 12% increase over the previous year). Sixty percent were young people under age 39, and 80% were from non-farming families.[24] In response to these achievements and expectations, MAFF launched a new "farming employment project" with a FY2008 supplementary budget. This project supports practical training so that a diverse array of people with a desire to take up farming can learn farming techniques and gain management expertise at agricultural production corporations and other entities. It has also launched a distinctive project informally called the "Country Work Corps" (officially called the "Model Project to Support the Training and Deployment of People to Vitalize Agriculture") to train people with leadership potential who can help vitalize rural areas. This project attempts to link — via NPOs, universities, businesses, and other entities — urban people who have interests in rural commuinities such as working or settling there (retirees, job-seekers, experts, students, and others) with rural areas that need new sustainers. While these are both noteworthy projects, the budgets allocated by the government are far too small in comparison with their importance. In addition to further innovating and improving the systems, consideration should be given to more fundamental measures.

In any event, the job of fostering and securing the new sustainers of agriculture and rural societies, who are indispensable for revitalizing Japan's rural societies and providing for rural sustainability, presents us with the crucial tasks of developing a strategic vision aimed at rebuilding the relationship between cities and rural areas and rigorously reinforcing the systematic initiatives based on that vision, which should include, more than anything else, creating an enabling environment for support from cities, interchange with cities, and for people to move from cities and settle in rural areas.

VI. Conclusion

For this collection of papers on "rural sustainability," we took up three basic problems (issues) while using as a springboard the initiatives under the "natural resource-based economies" project launched at Hitotsubashi University, and performed a cursory examination of several challenges raised by those three issues, with an especial focus on Japan's situation. The three issues are: (1) Agriculture and rural communities in political policy, (2) land use and resource management in

---

[24] Ibid., note 10, p. 84.

agriculture and rural societies, and (3) sustainers of agriculture and rural societies. This paper recognized the importance of the close mutual connections among the problems raised by these three issues, and for the first time proposed a unique conceptual framework called "natural resource-based economies," which can frame them in a comprehensive and integrated manner. Using that framework, we discussed from our own perspective the importance of the contemporary challenge of how to ensure the sustainability of agriculture and rural societies, which occupy a truly fundamental position.

To deal more convincingly with the issues raised in this paper, we intend to explore in greater depth a number of individual themes as part of the project. These include: (1) policy studies from the perspectives of environmental economics and resource economics on the sustainable use of the stock and flow of natural resources (renewable and non-renewable), (2) policy studies on the structure, positioning, and roles of natural resource-dependent industries in conserving, for example, biodiversity, traditional cultures, and landscapes, (3) policy studies on the organizations and institutions of the "commons-type management" of natural resources, (4) policy studies (including international comparative studies) on the institutions (especially funding and fiscal mechanisms) and governance which support industries and communities that are dependent on natural resources, (5) policy studies on domestic and international market trends and international trade rules (including, for example, WTO negotiations) on agriculture, forestry, and marine products, and (6) policy studies on the significance and roles of campaigns for sending farm-fresh produce directly to consumers, campaigns for local production for local consumption, the fair trade movement, green consumer campaigns, trust campaigns, and NGO and NPO sectors, and other consumer/citizen initiatives. These individual themes for policy studies are unavoidable if we are to delve deeper into the contemporary challenges facing "rural sustainability" as covered in this collection. We hope to have another opportunity to explore rural sustainability based on the progress made in the policy studies on those individual themes.

Citations

1. **Millennium Ecosystem Assessment (2005): *Ecosystem and Human Well-being: Synthesis*, Island Press.**
2. **Gretchen Daily (1997): *Nature's Services: Social Dependence on Natural Ecosystems*, Island Press.**
3. **R. David Simpson, Michael A. Toman, and Robert U. Ayres, ed. (2005): *Scarcity and Growth Revisited: Natural Resources and the Environment in the New Millennium*.**
4. **Satoshi Osawa, Satoru Okubo, Yoshinobu Kusumoto, and Takuya Mineta (2008): "A New Way of Conceiving 'Biodiversity Conservation' in Future Rural Area Planning," *Journal of Rural Planning Association*, vol. 27, no. 1 (in Japanese).**
5. **Hirobumi Uzawa (2000): *Social Common Capital*, Iwanami (in Japanese).**
6. **Shun'ichi Teranishi (2001): "Hirobumi Uzawa's *Social Common Capital*: The Prospect of 'Uzawa Economics' for 21st-Century Environmental Restoration," *Economist*, combined spring issued for February 1 and 9 (in Japanese).**
7. **The Newest Basic Plan on Food, Agriculture, and Rural Areas Editorial Committee (2006): *The Newest Basic Plan on Food, Agriculture, and Rural Areas*, Taisei Publishing (in Japanese).**
8. **Ministry of Agriculture, Forestry and Fisheries, ed. (2009): *2009 White Paper on Food, Agriculture and Rural Areas*, Saeki Printing (in Japanese).**
9. **Ministry of Agriculture, Forestry and Fisheries, ed. (2008): "Results of the Interim Assessment of the System for Direct Payments to Hilly and Mountainous Areas" (in Japanese).**
10. **Ministry of Agriculture, Forestry and Fisheries, ed. (2009): "Final Assessment of the System for Direct Payments to Hilly and Mountainous Areas" (in Japanese).**
11. **Motoyuki Goda, ed. (2001): *Direct Payments to Hilly and Mountainous Areas, and Environmental Conservation*, Ienohikari (in Japanese).**
12. **Yoichi Yamaura (2009): "Trends in Research on Hilly and Mountainous Area Agriculture Since the 1990S, with a Focus on Issues Surrounding the System for Direct Payments to Hilly and Mountainous Areas," in Shin'ichi Shogenji, ed., *Agricultural Policy in the Age of Reform: A Review of the Latest Policy Studies*, Norintokei Publishing (in Japanese).**
13. **Mikitaro Shobayashi (2009): "EU Agricultural and Environmental Policy,"**

***Transactions of the XXVI International Society of Soil Science,* National Institute for Agro-Environmental Sciences (in Japanese).**
14. **Daisuke Takahashi (2009): "Debate in Recent Years on Farmland System Debate, Primarily on the Matter of Farmland Conversion," in Shin'ichi Shogenji, ed., *Agricultural Policy in the Age of Reform: A Review of the Latest Policy Studies,* Norintokei Publishing (in Japanese).**
15. **Shun'ichi Teranishi (2005a): "Another Visit to Tenjinsaki: Learning from an Early Instance of the Trust-Type Nature Protection Movement in Japan," in *Contemporary Forestry,* July, pp. 14–15 (in Japanese).**
16. **Shun'ichi Teranishi (2005b): "Cost Allocation in Nature Protection: A Meditation on the Significance and Possibilities of the Commitment Principle," in *Contemporary Forestry,* August, pp. 14–15 (in Japanese).**
17. **Takeshi Fujiya (2008): "Cost and Financing for Nature Protection and Environmental Quality Conservation, with the UK National Trust as an Example," *Hitotsubashi Journal of Economics* (3) 1, pp. 45–69 (in Japanese).**
18. **Takeshi Murota, ed. (2009): *Local Commons in a Globalized World,* Minerva Publishing, 2009 (in Japanese).**
19. **Tokumi Odagiri (2009): *Rural and Mountain Village Revival: Transcending the Problem of "Marginal Villages,"* Iwanami Booklet No. 768, Iwanami (in Japanese).**
20. **Akira Ohno (2005): *An Introduction to the Environmental Sociology of Mountain Villages,* Rural Culture Association (in Japanese).**

Tree Growing Objectives of Smallholder Farmers in Claveria, Northern MinDanao, Philippines[1]

Canesio Predo[2] and Herminia Francisco[3]

Abstract

This study aimed to capture the underlying motives of smallholders for planting trees in their farms. Specifically, it aimed to identify the farm and household characteristics that might explain the underlying tree growing objectives of smallholder farmers, and draw policy implications for enhancing tree growing among farmers. The study was conducted in Claveria, northern Mindanao, Philippines. It made use of 192 farmer-respondents who practiced tree-based farming systems with corn being the dominant crop.

Empirical evidence from the principal component analysis indicated that smallholders' farm forestry is an investment with multi-objectives, primarily focusing on monetary and other economic objectives. The first component represents "employment, economic security and asset motive" of tree growing was related to labor income and self-employment, increase income from timber sales, asset motives, security in old age, speculative motive, etc. The second component interpreted to represent "recreation and aesthetic objective" was characterized by non-timber use of tree growing such as outdoor recreation, solitude and meditation, aesthetic value, and improved healthy residential environment. The variables relating to the objectives of restoring farm fertility and productivity, erosion control measure, nature protection, and making the environment cooler represented the third component, as "environmental protection and restoration objective."

Tree planting for monetary and economic objectives was significantly and positively influenced by farm distance from barangay center and inversely related to gender and education of household heads, household size, total annual cash income, and average farm distance from the nearest road. Similar variables were associated with recreation and aesthetic objectives of tree planting except on civil status. Environmental and restoration motive was negatively associated with farming experience of households. However, it was uniquely related to the age of household heads and knowledge level regarding tree-based systems. This finding has significant implications on agricultural technology adoption in general, and tree farming in particular.

Keywords: principal component analysis, smallholder farmers, tree growing, grasslands, Philippines

---

[1] Paper to be presented during the 1st Congress of East Asian Association of Environmental and Natural Resource Economics held on 18-19 August 2010 at Hokkaido University, Sapporo, Japan.

[2] Assistant Professor, Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines.

[3] Director, Economy and Environment Program for Southeast Asia (EEPSEA), International Development Research Centre, Regional Office for Southeast Asia and East Asia, 22 Cross Street #02-55, South Bridge Court, Singapore.

1. Introduction

Forest margins comprise an important geographical component of Philippine agriculture. These vast areas in the uplands are the results of a land use transformation from natural forest to grassland areas via shifting cultivation and consequently into permanent agriculture due to increasing population pressures in the uplands (Bandy et al. 1993; Garrity and Agustin 1995). Traditionally, shifting cultivation is sustainable with long fallow period. When fallow period shortens, soil fertility declines significantly due to increasing soil erosion, and has resulted in degraded grasslands that are generally acidic, with low organic matter and dry soil susceptible to soil erosion. In the Philippines, the environmental consequences of shifting cultivation in upland areas are severe and widespread with soil erosion as the worst environmental problems (World Bank 1989). Estimated total annual soil loss from the Philippines varied from 74.5 million tons (DENR 1992) to 80.6 million tons (Francisco 1994). Soil erosion is a natural process, however, it is greatly accelerated by human activities.

The intensive cultivation of upland areas without the adoption of appropriate soil conservation practices produce high rates of soil loss and threaten the long-term sustainable productivity of the upland resource base (Francisco 1998; Nelson and Cramb 1998). This has serious implications on the economic welfare of a growing upland population with few feasible livelihood alternatives. There is evidence that the future of low input shifting cultivation in the uplands is grim. Where economic viability is still being achieved, it is not likely to last as indicated by soil quality and long-term economic performance (Menz and Grist 1998). If smallholder farmers continue to practice intensive farming system without the application of new technology or inputs, returns to labor will fall to the point that most of these smallholder upland farms will cease to be viable (Menz and Grist 1998; Nelson et al. 1998; Magcale-Macandog et al.1998). For most smallholder farmers, the limited land area available implies that it is not financially feasible to reduce the cropped areas sufficiently to maintain yields and soil parameters at sustainable levels. The challenge therefore is to facilitate improved productivity and profitability of degraded uplands and at the same time maintain environmental quality of this resource for sustainable upland livelihood of smallholders.

Tree-based farming systems are potentially profitable alternatives for improving the productivity and sustainability of marginal upland areas. Tree growing is recognized to be effective in the control of *Imperata* and other grasses via shading (Menz and Grist, 1996; Gouyon, 1992). It also provides additional public benefits in the form of carbon fixation by sequestering atmospheric carbon through their growth process (Nowak, 1993). Tree growing is recognized as a practical way of removing large volume of greenhouse gases (GHGs), especially carbon dioxide (CO_2), from the atmosphere (Trexler and Haugen, 1995). CO_2 is the most abundant and important GHG under human control (Moura-Costa, 1996; Houghton, 1996) and it is expected to account for more than 50% of the radiative forcing of GHGs released from human activity over the next century (Houghton, 1996; Houghton *et al.*, 1990).

Apart from knowing the profitability of tree-based farming systems, it is also important to understand the underlying tree growing objectives of smallholder farmers as well as the socioeconomic circumstances that influence their motivation about the planting of trees. It is argued that understanding the motivations as well as the process by which farmers make tree-planting decisions will broaden the general population's perception and lead to an increase in the volume of timber grown on smallholder farms in *Imperata* grassland areas. Farmers' willingness to grow trees depends on many factors and different motives, and if government or non-government organizations intend to convince farmers to invest and grow more trees, these motivating factors must first be understood.

This paper aims to analyze the motivation of smallholder farmers for planting trees in their farms. Specifically, it aims to (1) determine the general underlying objectives of farmers for investing in tree growing from the response on a number of stated social, economic and environmental objectives; (2) identify the farm and household characteristics that might explain the underlying tree growing objectives of smallholder farmers, and (3) draw policy implications for enhancing tree growing among smallholder farmers. To answer these objectives, the rest of the paper is organized as follows. Section 2 presents the methodology describing the survey design and data collection, selection of study area and respondents, and data analysis employed including the principal component analysis of stated objectives. This is followed by brief description of the study area in section 3. The results and discussion of findings are presented in section 4. The last section discusses the conclusions, policy implications and recommendations of the study.

2. Methodology

2.1 Survey Design and Data Collection

The survey was conducted in Claveria, Misamis Oriental, Philippines. The barangays included in the survey were selected primarily based on the presence of mixed land use systems and secondly, on accessibility. From the selected barangays, a targeted selection of respondents was employed for the household survey. Households with farms contiguous to each other were selected to cover four study sites. A total of 192 farmer-respondents were interviewed, from which tree-based farming systems adopters and non-adopters were identified based on their current land use, particularly on whether or not they have planted trees on their farms. This method of classifying the respondents served as the basis in the analysis of data.

This study utilized both primary and secondary data. Primary data such as socioeconomic and farm characteristics were collected through survey using pre-tested structured interview schedule and key informant interview. Other primary data collected include landholding, land use pattern, tree growing investment objectives, and other relevant information.

Secondary data were collected from previous surveys, literatures and reports from various research institutions, government offices and agencies.

2.2 Selection of Study Area

The study was conducted in a representative *Imperata*-dominated grassland area in the Philippines that meets the characteristics of interest for the study. The following criteria were used in selecting the study area. First, the area has been subjected to long-term government and non-government interventions relating to soil conservation practices. Second, there is significant adoption of soil conservation practices and transformation of *Imperata* grassland into tree-based land use systems. Based on the above criteria, Claveria, Misamis Oriental in Mindanao has been selected for the study. Since 1987, the International Rice Research Institute (IRRI), and starting 1993, the International Centre for Research in Agroforestry (ICRAF) have been conducting research on contour hedgerow technologies for soil erosion control in Claveria. The availability of biophysical and other secondary data for model calibration was also considered in the selection of the site.

2.3 Selection of Respondents

The barangays included in the survey were selected primarily based on the presence of mixed land use systems and secondly, on accessibility. From the selected barangays, a targeted selection of respondents was employed for the household survey. Households with farms contiguous to each other were selected to cover four study sites. A total of 192 farmer-respondents were interviewed, from which tree-based farming systems adopters and non-adopters were identified based on their current land use, particularly on whether or not they have planted trees on their farms. This method of classifying the respondents served as the basis in the analysis of data.

2.4 Data Analysis

2.4.1 Descriptive Analysis

Descriptive statistics was used to describe and compare household and farm characteristics of the respondents. Sample t-test and one-way analysis of variance were also used to compare means of selected variables used in the analysis.

2.4.2 Principal Component Analysis

The potential goals of farmers in planting trees may include economic and non-economic factors, including recreational, emotional, and aesthetic considerations. In order to capture the underlying reasons of smallholders for planting trees in their farms, 18 different objectives related to tree growing were presented to the respondents. They were asked to assess the importance of each objective being presented using a four-point likert scale (4=very important, 3=important, 2=less important, 1=not important).

With the large number of observed variables on tree growing objectives, a principal component analysis (PCA) was done to reduce the original variables into few variables that would represent the underlying tree growing objectives of farmers. PCA is a variable reduction procedure to analyze observed variable that would result in a relatively small number of (interpretable) components which account for most of the variance in a set of observed variables. Technically, a principal component is defined as a linear combination of optimally-weighted observed variables. The eigenvalue criterion and scree test were used to determine the number of extracted components from the observed data. To measure the reliability of the solution, Carmine's theta (θ) was computed for the unrotated solution as follows:

$$\theta = \frac{n}{n-1}\left(1 - \frac{1}{\lambda_1}\right)$$

where n is the number of items in the total principal component analysis and λ_1 is the largest (the first) eigenvalue. Theta may be considered a maximized Cronbach's alpha coefficient (Carmines and Zeller 1979).

Orthogonal rotated solution was done to obtain uncorrelated components (and factor scores) using varimax rotation method. The general formula to compute factor scores on k^{th} component extracted (created) in a PCA is as follows:

$$C_k = b_{k1}(X_1) + b_{k2}(X_2) + \ldots + b_{kp}(X_p)$$

where C_k = the subject's scores on k^{th} principal component extracted/created;
b_{kp} = the regression coefficient (or weight) for observed variable p, as used in creating principal component k; and
X_p = the subject's score on observed variable p.

The underlying tree growing objectives were determined from the loading patterns of each individual original objective in the extracted components. On the basis of statistical power of 0.80 (at n=200) in interpreting the rotated factor pattern, a variable was said to load on a given component if the factor loading was 0.40 or greater (in absolute value), and less than 0.40 for any other component (Hair et al. 1998). If a variable has high loading on more than one component, then that variable is excluded in the interpretation because it does not have pure measures of any underlying objectives. Factor scores of all meaningful components extracted were estimated and used as dependent variables in the succeeding analysis.

2.4.3 Specification of Tree Growing Objective Function

Factor scores of each extracted component were regressed to relevant household and farm characteristics to shed light on the variable that might explain the underlying tree growing objectives of smallholder farmers. The tree growing (underlying) objective function was specified as follows and estimated using ordinary least squares (OLS) regression:

$$\begin{aligned} C_k = {} & \beta_0 + \beta_1 AGE + \beta_2 SEX + \beta_3 CSTATDUM + \beta_4 EDUCYR \\ & + \beta_5 HSIZE + \beta_6 FEXPH + \beta_7 KSCORE + \beta_8 TENURDUM \\ & + \beta_9 TCASHINC + \beta_{10} PARCEL + \beta_{11} FAREA + \beta_{12} YRTREE \\ & + \beta_{13} DHOME + \beta_{14} DROAD + \beta_{15} DBRGY + \beta_{16} DTOWN + \varepsilon \end{aligned}$$

where:

C_k	=	scores of k principal components retained
AGE	=	age of the respondents (years)
SEX	=	dummy for sex: 1 if male, 0 otherwise
CSTATDUM	=	dummy for civil status: 1 if married, 0 otherwise
EDUCYR	=	educational attainment (years)
HSIZE	=	household size
FEXPH	=	farming experience of household head (years)

KSCORE	=	knowledge score (%) of the respondents about soil conservation and tree-based systems (see below the formula in measuring knowledge score)
TENURDUM	=	dummy for tenure status: 1 if owner, 0 otherwise
TCASHINC	=	household total annual cash income (PHP)
PARCEL	=	number of farm parcels
FAREA	=	farm area (ha)
YRTREE	=	years of adopting tree-based farming systems
DHOME	=	distance of farm parcels from home (km)
DROAD	=	distance of farm parcels from nearest road (km)
DBRGY	=	distance of farm parcels from barangay road (km)
DTOWN	=	distance of farm parcels from town center (km)
β's	=	parameters to be estimated
ε	=	error term assumed to be normal and independently distributed

2.4.4 Measuring Knowledge Score of Farmers on Tree-based Land Use Systems

Knowledge level of smallholder farmers on soil conservation and tree-based land use systems was assessed using a set of 20 multiple choice questions/statements answerable by yes, no or I don't know. The questions included the topics on land use management practices, tree-based systems characteristics and their economics and ecological consequences. A set of key answers was then used to evaluate farmers' knowledge score (KSCORE) using the formula developed by Romney *et al*. (1986):

$$\text{KSCORE} = \frac{(RQ_n \text{ x } n) - 1}{(n-1)}$$

where, RQ_n is the percentage of right answers to questions with *n* choices.

3. Description of the Study Area

Claveria is the only landlocked municipality among the 24 municipalities of the province of Misamis Oriental. It lies at approximately 124°45' to 125°25' on the east longitude and 8°34' to 8°55' on the north latitude. It is bounded by the province of Agusan del Norte on the east; the province of Bukidnon on the south; the coastal municipalities (Balingasag, Lagonglong, Salay, Sugbongcogon, Kinoguitan, Balingoan, Medina and Gingoog) on its north; and the municipalities of Jasaan and Villanueva on the west. Claveria is situated 40.26 km northeast of Cagayan de Oro City, the capital of Misamis Oriental province (CMPDO, 2000).

The municipality of Claveria occupies 82,475.31 ha of uplands in the province, which represents 1/3 of the total land area of Misamis Oriental province (CMPDO, 2000). It is a volcanic plateau ascending abruptly from 400 meters above sea level (masl) in the west to about 2,500 masl in the east. About 43,023.30 ha. (38%) are declared alienable and disposable land, the rest is public land classified either as timberland, forest reserve or natural park (Mercado, 1995).

The soils in Claveria are representative of many well-drained, volcanic clay soils in the tropical uplands. Developed from weathered igneous rock and pyroclastic materials, they are highly leachable, acidic and thus of comparatively low fertility (Mercado, 1995). Claveria's soils have been characterized as deep soils of more than one meter depth and classified as fine, mixed isohyperthermic Ultic Haplorthox or Oxic Dystropept soils (Garrity and Agustin, 1995). Most soils have a low pH-value (3.9-5.8), low cation exchange capacity (CEC), low to moderate in organic matter content, low in available phosphorus and exchangeable potassium and are prone to aluminum toxicity (Garrity and Agustin, 1995).

Claveria's climate is characterized by a high degree of variation due to weather patterns outside the typhoon belt and its varied topography. The average annual temperature in Claveria is approximately 24^{o}C and rarely exceeds 30^{o}C, while relative humidity remains about 80% (CMPDO, 2000). Annual rainfall ranges from 1,800 to 3,500 mm, depending on the elevation and local topography, and falls mostly between June and December (Mercado, 1995). Rainfall is distributed seasonally among five to six "wet" months of June to October/November (>200 mm of rainfall) and three to four "dry" months of February/March to May (<100 mm of rainfall). Although the region is considered to have a favorable environment for rainfed agriculture, rainfall is highly variable from year to year (Mandac *et al* ., 1987). Major crops planted include rootcrops, tomato, and maize, being the dominant crop as source of staple food and animal feed. Tree farming of fast-growing tree species like *Gmelina arborea*, *Acacia mangium*, *Eucalyptus deglupta and Swietenia macrophylla* is emerging in the area (Mercado, 1995). Timber trees are planted usually along farm boundaries or as pure stand.

4. Results and Discussion

4.1 Household and Farm Characteristics of the Respondents

The respondents of the study were smallholder upland farmers. During the interview the respondents were asked if they have planted timber, fruit trees and other tree species in their farms. Those who answered 'yes' were classified tree-based farming system adopters (TBFSA), otherwise the farmers were considered as non-adopters of tree-based farming systems (NTBFS). Survey results indicated that for the total 192 farmers interviewed about 165 farmers were TBFSA and 27 were NTBFS.

Farmers under TBFSA category were further subdivided into three classes based on the number of years of adoption of the tree-based farming systems: A1 (late adopter: 5 years and below), A2 (intermediate adopter: 6-10 years), A3 (early adopter: 11 years and above). Similarly, farmers under NTBFS category were also labeled A0 (non-adopter).

4.1.1 Socio-Demographic Characteristics

Majority of the respondents (76.6%) were 31-60 years old with an average age of 45 years (Table 1). Similar trend was observed among the tree-based system adopters, that is, about

83%, 79%, and 72% of A1, A2, and A3 farmers, respectively, were 31-60 years of age. On the other hand, about 59% only for non-adopters of tree-based systems (A0) belonged to this age bracket. The mean age of different tree-based system adopters ranged from 43 to 50 years while the mean age of non-adopters was 39 years (Table 1). Upland farmers who invested in tree-based farming systems were significantly older than non-adopters except for recent adopters (i.e., those who started to plant trees five years ago and later).

Table 1. Distribution of selected household characteristics of the respondents by adoption category, Claveria, Misamis Oriental, Philippines.

VARIABLE	PERCENT				
	A0 [n=27]	A1 [n=81]	A2 [n=48]	A3 [n=36]	ALL [n=192]
Age (years)					
Below 30	29.6	9.9	4.2	5.6	10.4
31 – 40	33.3	39.5	25.0	11.1	29.7
41 – 50	22.2	25.9	27.1	38.9	28.1
51 – 60	3.7	17.3	27.1	22.2	18.8
Above 60	11.1	7.4	16.7	22.2	13.0
Total	100.0	100.0	100.0	100.0	100.0
*Mean***	*38.70a*	*42.89a*	*48.73b*	*49.94b*	*45.08*
(SD)	*(12.26)*	*(12.03)*	*(11.47)*	*(13.11)*	*(12.67)*
Range	*24-65*	*18-86*	*26-72*	*22-78*	*18-86*
Gender					
Male	92.6	91.4	89.6	94.4	91.7
Female	7.4	8.6	10.4	5.6	8.3
Total	100.0	100.0	100.0	100.0	100.0
Level of education (years)					
No education	0.0	0.0	2.1	0.0	0.5
Elementary (1-4)	33.3	33.3	27.1	30.6	31.3
Primary (5-6)	44.4	24.7	31.3	30.6	30.2
Secondary (7-10)	22.2	33.3	33.3	27.8	30.7
Tertiary (11-14)	0.0	8.6	6.3	11.1	7.3
Total	100.0	100.0	100.0	100.0	100.0
Mean^{ns}	5.78a	6.32a	6.19a	6.33a	6.21
(SD)	(2.17)	(3.26)	(2.96)	(3.50)	(3.08)
Range	1-10	1-14	0-14	1-14	0-14

Table 1. Cont'd…

VARIABLE	PERCENT				
	A0 [n=27]	A1 [n=81]	A2 [n=48]	A3 [n=36]	ALL [n=192]
Household size					
2-3	25.9	23.5	10.4	13.9	18.8
4-6	40.7	45.7	50.0	38.9	44.8
7-9	33.3	22.2	29.2	33.3	27.6
10-11	0.0	8.6	10.4	13.9	8.9
Total	100.0	100.0	100.0	100.0	100.0
Mean ^{ns}	5.07a	5.56a	5.98a	6.31a	5.73
(SD)	(2.18)	(2.34)	(2.23)	(2.51)	(2.34)
Range	2-9	2-11	2-11	2-11	2-11
Civil status					
Single	0.0	0.0	2.1	0.0	0.5
Married	100.0	97.5	91.7	94.4	95.8
Widow/widower	0.0	2.5	6.3	5.6	3.6
Total	100.0	100.0	100.0	100.0	100.0
Farming experience (years)					
10 years and below	59.3	33.3	27.1	8.3	30.7
11 – 20	18.5	35.8	25.0	33.3	30.2
21 – 30	18.5	18.5	25.0	36.1	23.4
31 and above	3.7	12.3	22.9	22.2	15.6
Total	100.0	100.0	100.0	100.0	100.0
*Mean***	12.56a	17.43a	21.79ab	23.81b	19.03
(SD)	(9.59)	(11.77)	(13.78)	(11.97)	(12.54)

** = significant at 1% level; ns = not significant
Means within row having the same letters are not significantly different at 5% level using Tukey HSD test.

Majority (92%) of the upland farmers who make decisions about their upland farming activities were males. Both tree-based system adopters (90 to 94%) and non-adopters (93%) were predominantly males (Table 1). Regarding their civil status, it was found that majority of the tree-based system adopters (92% to 98%) and all (100%) non-adopters were married. Overall, about 96% of the total respondents were married (Table 1).

In terms of educational attainment, on the average, upland farmers reached primary level, spending at least six years in school (Table 1). More of the tree-based system adopters (33% for A1 and A2; 28% for A3 respondents) reached at least the secondary level compared to the non-adopters (22%). The mean educational attainment of adopters (6.32 for A1, 6.19 for A2, and 6.33 years for A3) was not significantly different compared with the non-adopters (5.78 years).

The household size of the upland farmers surveyed ranged from 2-11 members (Table 1). Of the total respondents, about 44% have 4-6 household members and at least six household members on the average. There were approximately 39% to 50% of the tree-based system adopters who have 4-6 family members while only 41% of non-adopters also have 4-6 to six family members. However, mean household size of tree-based system adopters was not significantly different from their non-adopter counterparts.

Majority of the total respondents (60.9%) have been farming for 20 years or less (Table 1). Similar pattern was observed for non-adopters (77.8%) and for late (A1) and intermediate (A2) adopters of tree-based systems (69.1% for A1, 52.1% for A2). Meanwhile, majority (69.4%) of early adopters (A3), i.e., farmers who started planting trees 11 years and above, were farming for 11-30 years (Table 1). The average years of farming experience between adopters and non-adopters has been found to be highly significant. Multiple comparisons across type of respondents show that the mean years of farming among non-adopters (12.56 yrs), late adopters (17.43 yrs), and intermediate adopters (21.79 yrs) were not significantly different at 5% level using Tukey HSD test. However, the years of farming experience among non-adopters, late adopters and early adopters were found to be significantly different from each other.

4.1.2 Annual Household Cash Income

The sources of annual cash income of upland farmers included farm, off-farm, and non-farm (Table 2). Among these, farm income provided the highest cash income for both adopter and non-adopters while the off-farm source provided the least income for adopters, and the non-farm source for non-adopters.

Farm income. Farm income comprised the following sources: (i) annual crops such as corn, lowland and upland rice; (ii) perennial crops such as mango, coffee, coconut, and banana; and (iii) animal and livestock production. Table 2 shows that the average farm income over the last 12 months for tree-based system adopters (P32,263 for A1, P36,934 for A2, P51,691 for A3) was significantly higher than non-adopters (P15,379). Further test indicated, however, that average farm income among tree-based adopters was not significantly different from each other while average farm income for non-adopters was significantly different only from early adopters (A3) of tree-based systems. This partly suggests that higher farm income may be due to increased farm fertility and productivity associated with the incorporation of trees into the farming system.

Off-farm income. Off-farm income was commonly obtained from off-farm wage work as hired laborer on other individuals' farm. Mean off-farm income between adopters and non-adopters was significantly different from zero. On the average, the non-adopters earned more off-farm income than the adopters. The non-adopters earned about P6,689 while the adopters earned about P4,054 for A1, P2,147 for A2, and P877 over the last 12 months from off-farm activities (Table 2). Nonetheless, the off-farm income of non-adopters was not significantly different compared with the A1 adopters.

Table 2. Descriptive statistics of farm, off-farm, non-farm and total annual cash income (Pesos) of adopters and non-adopters of tree-based farming systems, Claveria, Misamis Oriental, Philippines.

INCOME SOURCE	PERCENT				
	A0 [n=27]	A1 [n=81]	A2 [n=48]	A3 [n=36]	ALL [n=192]
A. Farm Income*	15379.41 a	32263.08 ab	36933.52 ab	51691.10 b	34699.18
	(19589.06)	(54924.75)	(46423.38)	(50545.10)	(49246.52)
B. Off-farm Income**	6688.89 a	4054.07 ab	2146.67 b	876.67 c	3351.98
	(6484.59)	(5319.48)	(3564.36)	(2257.57)	(4993.94)
C. Non-farm Income^{ns}	3571.85 a	4852.35 a	11806.25 a	10722.78 a	7511.46
	(9185.63)	(10879.29)	(26357.17)	(17526.22)	(17322.43)
Total Cash Income*	25640.15 a	41169.50 ab	50886.43 ab	63290.55 b	45562.61
	(20175.71)	(54874.65)	(50655.89)	(51810.00)	(50701.28)

**, * = significant at 1%, 5% level; ns = not significant.
Note: 1) Means within row having the same letters are not significantly different at 5% level using Tukey HSD test.
2) Figures in parenthesis are standard deviations.

Non-farm income. Non-farm income was derived from non-farm wage work, land rent, small business operation, and remittances from household members working outside the community. The adopters earned relatively higher non-farm income (P4,852 for A1, P11,806, P10,723 for A3) than the non-adopters (P3,572), although the difference was not significantly different at 5% level (Table 2).

Total annual cash income. On the average, upland farmers earned about P45,463 over the last 12 months of cash income from all sources. The total annual cash income between adopters and non-adopters was significantly different at 5% level (Table 2). While total annual cash income among adopters (P41,170 for A1, P50,886 for A2, P63,291 for A3) was not significantly different from each other, A3 adopters earned significantly higher total annual cash income than the non-adopters (P26,640).

4.1.3 Farm Characteristics of the Respondents

Majority (92%) of the upland farmers had one to two farm parcels (Table 3). On the average, the tree-based system adopters had slightly higher number of farm parcels (1.40 for A1, 1.58 for A2, 1.56 for A3 adopters) than the non-adopters (1.15). Multiple comparison of means indicated that only the number of parcels between A2 adopters and non-adopters was significantly different at 5% level.

Table 3. Distribution of parcels and farm size of adopters and non-adopters of tree-based farming systems, Claveria, Misamis Oriental, Philippines.

FARM CHARACTERISTIC	PERCENT				
	A0 [n=27]	A1 [n=81]	A2 [n=48]	A3 [n=36]	ALL [n=192]
No. of parcels					
1-2	100.0	92.6	85.4	94.4	92.2
3-4	0.0	7.4	14.6	5.6	7.8
Total	100.0	100.0	100.0	100.0	100.0
*Mean**	1.15a	1.40ab	1.58c	1.56abc	1.44
Range	1-2	1-3	1-3	1-4	1-4
Total farm size (ha)**					
Less than 1	44.4	16.0	8.3	2.8	15.6
1.00 – 2.00	48.1	55.6	41.7	52.8	50.5
2.01 – 4.00	7.4	25.9	45.8	33.3	29.7
4.01 & above	0.0	2.5	2.5	11.1	4.2
Total	100.0	100.0	100.0	100.0	100.0
Mean	1.09a	1.82ab	2.38bc	2.97c	2.07
Range	0.25-2.75	0.25-11	0.25-10	0.75-18	0.25-18

*,** = significant at 5% and 1% level, respectively
Means within row having the same letters are not significantly different at 5% level using Tukey HSD test.

Total farm area ranged from 0.25 to 18 ha, with an average of 2.08 ha for the total respondents (Table 3). The adopters (specifically A2 and A3) of tree-based farming systems have significantly higher average farm size (2.38 ha for A2, and 2.97 ha for A3) than the non-adopters (1.09 ha). In terms of distribution, almost similar proportion of tree growers (55.6% for A1, 41.7% for A2, and 52.8% for A3) and non-tree growers (48.1%) had farm size of 1-2 ha. On the other hand, there are about 26-46% of the former had landholdings of 2.01 to 4.0 ha while less than 10% of the latter had that farm size. Overall, majority of the upland farmers (80.2%) have 1-4 ha of farm landholdings.

With regards to land tenure, the respondents owned the majority (59%) of the total farm parcels they were cultivating (Table 4). The tree-based system adopters owned about 52-75% percent of their farms while the non-adopters owned about 26 percent only of their farms parcels. The rest of their farms were tenanted and rented/leased. It is noteworthy however to mention that majority of non-tree growing farmers (42%) were tenants of the farm parcels they tilled while only about 13-29% of the tree-based system adopters were tenants. For farm parcels owned by farmers, majority of both adopters and non-adopters have titled to the land they cultivated (39%). The second highest proportion of land ownership was the certificate of land transfer (25%), followed by ownership with no formal document, tax declaration, certificate of stewardship contract, and mortgage (Table 4).

Table 4. Distribution of parcels by tenure, ownership type, and adoption category of respondents, Claveria, Misamis Oriental, Philippines.

FARM PARCEL CHARACTERISTIC	PERCENT				
	A0	A1	A2	A3	ALL
Tenure status	[n=31]	[n=113]	[n=76]	[n=57]	[n=277]
Owner	25.8	52.2	75.0	68.4	58.8
Tenant	41.9	29.2	13.2	19.3	24.2
Rented/Leased	32.3	18.6	11.8	12.3	17.0
Total	100.0	100.0	100.0	100.0	100.0
Type of ownership	[n=8]	[n=59]	[n=57]	[n=39]	[n=163]
Titled	37.5	39.0	33.3	46.2	38.7
Certificate of land transfer	25.0	20.3	29.8	25.6	25.2
Certificate of stewardship contract	0.0	8.5	0.0	0.0	3.1
Mortgage	0.0	1.7	5.3	0.0	2.5
Tax declaration	12.5	11.9	15.8	17.9	14.7
No formal document	25.0	18.6	15.8	10.3	16.0
Total	100.0	100.0	100.0	100.0	100.0

4.1.4 Membership in Organizations

Upland farmers in Claveria were either members or non-members in farming-related organizations in the community. Results show that majority of the tree-based adopters (68 to 75%) were members of farmers' organization while only about 41% of the non-adopter farmers (Table 5). This indicates that farmers who invested in tree growing are mostly likely to participate in farmer-related organizations. For the total respondents, approximately two-thirds (67%) were members and the rest were non-members.

In terms of number of organizations participated by farmers, majority of the tree-based system adopters (83.33 to 87.27%) and all of the non-adopters have been members in only one organization; however, the difference was not statistically significant.

4.1.5 Knowledge of Upland Farmers on Tree-based Farming Systems

A set of multiple choice questions/statements (20 items answerable by either yes, no or I don't know) was administered to the upland farmers to obtain their knowledge level on soil conservation and tree-based systems. The questions included the topics on land use management practices, tree-based systems characteristics and their economics and ecological consequences. All respondents were asked to answer the 20-item questions and the response score was obtained for all the questions. The mean response score for each question and the overall knowledge (scientific) scores were computed using the formula of Romney[4] *et al*. (1986).

[4] Refer to the methodology section for more details.

Table 5. Membership in farmer's organization of adopters and non-adopters of tree-based farming systems, Claveria, Misamis Oriental, Philippines.

VARIABLE	PERCENT				
	A0 [n=27]	A1 [n=81]	A2 [n=48]	A3 [n=36]	ALL [n=192]
Membership in Organization					
Member	40.74	67.90	75.00	75.00	67.19
Not member	59.26	32.10	25.00	25.00	32.81
Total	100.00	100.00	100.00	100.00	100.00
Number of Organizations	[n=11]	[n=55]	[n=36]	[n=27]	[n=129]
1	100.00	87.27	83.33	85.19	86.82
2 – 3	-	12.73	16.67	14.81	13.18
Total	100.00	100.00	100.00	100.00	100.00
Mean^{ns}	*1.00*	*1.13*	*1.19*	*1.19*	*1.15*
Std. Dev.	*0.00*	*0.34*	*0.47*	*0.48*	*0.40*

ns = not significant

Overall, the adopters have significantly higher mean score (83 to 87%) than non-adopters (45%) for all questions (Table 6). This suggests that the adopters were more knowledgeable than the non-adopters about the topics/questions being asked. Among tree-based system adopters, on the other hand, the mean score was not significantly different from each other. In terms of distribution, it can be noted that majority of the adopters exhibited high knowledge score (70% and above) while non-adopters were mostly considered to have medium knowledge score (35 to 69%).

Table 6. Knowledge scores (%) of adopters and non-adopters of tree-based farming systems, Claveria, Misamis Oriental, Mindanao, Philippines.

KNOWLEDGE SCORE (%)	PERCENT				
	A0 [n=27]	A1 [n=81]	A2 [n=48]	A3 [n=36]	ALL [n=192]
Low (34 & below)	22.22	-	-	-	3.13
Medium (35 thru 69)	70.37	14.81	8.33	8.33	19.79
High (70 and above)	7.41	85.19	91.67	91.67	77.08
Total	100.00	100.00	100.00	100.00	100.00
	DESCRIPTIVE STATISTICS				
Mean**	45.00 a	82.78 b	86.72 b	86.46 b	79.14
Std. Dev.	15.70	13.54	11.50	11.03	18.98
Minimum	2.50	47.50	62.50	55.00	2.50
Maximum	70.00	100.00	100.00	100.00	100.00

**Significant at 99% confidence level.

4.2 Components of Tree Growing Objectives

Based on the eigenvalue criterion and scree test results, only the first three components were retained and have meaningful interpretation to represent the underlying tree growing objectives of farmers. The reliability of the solution was good (Carmines' theta =0.88) and the explained proportion of the total variation of the original variable was 51% for the three components combined. Likewise, the Kaiser-Meyer-Olkin measure of sampling adequacy was also good to warrant interpretation of results.

The variables and the corresponding factor loadings are presented in Table 7. None of the variables have high loadings on more than one component, so all variables were included in the analysis. Ten variables were found to load on the first component. These variables described various monetary objectives, asset motives and other economic aspects of smallholder tree growing objectives. These concerned labor income and self-employment, increase income from timber sales, asset motives, security in old age, and speculative motive. This dimension was taken to represent "employment, economic security and asset motive" of tree growing. The second component was characterized by non-timber use of tree growing such as outdoor recreation, solitude and meditation, aesthetic value, and improved healthy residential environment. The principal component was interpreted to represent "recreation and aesthetic objective". Finally, variables relating to the objectives of restoring farm fertility and productivity, erosion control measure, nature protection, and making the environment cooler were loading high on the third component, which was subsequently labeled as "environmental protection and restoration objective."

Empirical evidence from the principal component analysis indicated that smallholders' farm forestry is an investment with multi-objectives, primarily focussing on monetary and other economic objectives. This finding has significant implications on agricultural technology adoption in general, and tree farming in particular. Thus, it is likewise important to know the farmers' characteristics and conditions that would likely influence tree growing potential goals and objectives.

4.3 Factors Influencing Farmers' Tree Growing Objectives

The relationships between the three underlying tree growing objectives, and household and farm characteristics were examined using ordinary least squares (OLS) regressions. The goodness-of-fit of the model for each objective was considered satisfactory and significant (Table 8).

Table 7. Principal Components of Farmers' Tree Growing Objectives, Claveria, Misamis Oriental, Philippines.

	EMPLOYMENT, ECONOMIC SECURITY & ASSET MOTIVE	*RECREATION & AESTHETIC OBJECTIVE*	*ENVIRONMENTAL PROTECTION & RESTORATION OBJECTIVE*
Outdoor recreation	0.18	0.79*	0.08
Solitude and meditation	0.14	0.86*	0.05
Aesthetic value	0.09	0.81*	0.19
Nature protection	0.07	0.06	0.63*
Healthy residential environment	-0.03	0.62*	0.16
Help make the environment cooler	0.26	0.20	0.48*
Erosion control measure	0.18	0.26	0.63*
Restore farm fertility and productivity	0.27	0.06	0.74*
Source of fuelwood	0.44*	0.34	0.07
Labor income and self-employment	0.81*	0.15	-0.20
Increase income from timber sales	0.60*	0.07	0.19
Timber for household use	0.48*	-0.06	0.18
Source of funds for investment	0.42*	0.33	0.37
Asset motive	0.69*	-0.01	0.29
Security against inflation	0.47*	0.36	0.17
Security in old age	0.71*	0.01	0.36
Speculative motive	0.65*	0.37	0.17
Bequest motive	0.59*	0.16	0.36
Variance explained (%)	21.23	17.03	12.75
Kaiser-Meyer-Olkin measure of sampling adequacy	0.86		
Carmines' theta	0.88		
N	165		

4.3.1 Monetary, Economic Security and Asset Motive

Tree planting for monetary and economic objectives was found to be significantly and positively influenced by farm distance from barangay center and inversely related to the sex and education of household heads, household size, total annual cash income, and average farm distance from the nearest road (Table 8). Households whose farm parcels are located relatively far from the barangay center are more likely to consider tree growing for economic security and asset motives. This is probably because farmers consider tree growing in distant farms as the appropriate land use option for long-term investments. Farms located near the barangay center are fairly accessible that makes long-term investments like tree growing unattractive relative to food crop and other cash crop production. Further, empirical evidence was shown by the negative coefficient for the distance of farm from nearest road, which serves as proxy variable for access.

Table 8. Ordinary Least Squares (OLS) Regression Estimates for Factor Score of Tree Growing Objectives and Household and Farm Characteristics, Claveria, Misamis Oriental, Philippines,

VARIABLE	EMPLOYMENT, ECONOMIC SECURITY & ASSET MOTIVE		RECREATION & AESTHETIC OBJECTIVE		ENVIRONMENTAL PROTECTION & RESTORATION OBJECTIVE	
	Coef.	T-value	Coef.	T-value	Coef.	T-value
CONSTANT	1.45	1.65	0.24	0.28	3.05 [a]	3.53
AGE	-0.01	-0.91	0.00	0.43	0.03 [a]	3.20
SEX	-0.59 [b]	-2.13	-0.37	-1.32	0.02	0.07
CSTATDUM	-0.25	-0.68	0.66 [c]	1.75	0.34	0.93
EDUCYR	-0.05 [c]	-1.84	-0.02	-0.84	0.00	0.08
HSIZE	-0.06 [c]	-1.82	0.07 [c]	1.92	-0.05	-1.57
FEXPH	-0.01	-0.57	-0.03 [a]	-3.30	-0.02 [a]	-2.72
KSCORE	0.00	0.30	0.00	-0.00	0.02 [a]	4.05
TENURDUM	-0.09	-0.55	-0.02	-0.10	0.04	0.23
TCASHINC	-2.9E-06 [d]	-1.58	2.9E-06 [d]	1.55	-1.6E-06	-0.90
PARCEL	0.16	1.26	0.04	0.34	-0.00	-0.02
FAREA	0.04	0.77	0.02	0.45	0.05	0.91
YRTREE	0.01	0.70	0.02	1.01	-0.00	-0.34
DHOME	0.08	0.62	-0.02	-0.14	-0.06	-0.51
DROAD	-0.50 [a]	-3.58	-0.01	-0.06	-0.22	-1.57
DBRGY	0.09 [c]	1.76	-0.05	-0.99	0.01	0.26
DTOWN	0.02	0.57	-0.03	-1.34	0.01	0.45
R^2	0.21		0.18		0.23	
F (16, 148)	2.40 [a]		2.08 [b]		2.70 [a]	
N	165		165		165	

[a, b, c, d] refer to significance at 1%, 5%, 10%, 15% level, respectively

Tree farming has been considered to provide employment and economic opportunities for female than male farmers. This implies that greater participation of women in farm decision-making would likely increase adoption of tree-based farming systems since they perceive more benefits than costs. If this is the case, it is important to highlight the role of women in any upland development projects. On the other hand, the negative effect of education indicates that economic motives of tree growing diminishes as education level increases. This may be because households with higher educational attainment have relatively more economic opportunities other than tree growing. Moreover, more educated households will probably plant trees in the farm for other reasons such as recreation, environmental protection and restoration. In fact, education was positively related to environmental protection and restoration motives of tree planting, although not statistically significant.

The inverse relationship between household size and economic and asset motives implies that maybe large households do not consider tree growing to provide income for subsistence simply because they probably could not afford to compromise their immediate household needs. Further, those households with higher annual cash income have planted trees for other non-monetary motives. Similar to household size, this result suggests that households' dependence on trees for employment, economic and asset motives diminishes as total annual cash income increases. As total annual cash income increases, the primary consideration has probably shifted from monetary motive to non-timber benefits as manifested by the positive coefficient of annual cash income for recreation and aesthetic reasons.

4.3.2 Recreation and Aesthetic Objective

Variables associated with recreation and aesthetic objectives of tree planting were similar to the variables influencing the economic objectives of tree planting except on civil status. The sign of significant variables was however, in opposite direction (Table 8). Civil status was significant and positively related to recreation and aesthetic component, which means that married households are likely to incorporate trees in the farm primarily for leisure and relaxation purposes than unmarried farmers. In consonance with civil status, household size was positively related to recreation objective, implying that households having large families tend to use farm forests as a destination for recreation activities. It is plausible for households with relatively more family members to think in this manner since undertaking recreation activities elsewhere requires a bigger household budget.

As expected, annual cash income was positively related to the recreation objective in tree growing since farmers could afford to devote extra time for leisure instead of working in the farm. Unexpectedly, farming experience was inversely related to recreation motive, which means that more experienced farmers would value less the recreation and aesthetic benefits of tree growing. Usually experienced farmers are expected to have more time for non-farming activities. This result can probably be explained by the subsistence nature of farming households included in the survey.

4.3.3 Environmental Protection and Restoration Objective

Similar to recreation motive, environmental and restoration motive was negatively associated with farming experience of households (Table 8). However, it was uniquely related to the age of household heads and knowledge level (score) regarding tree-based systems. Older farmers are likely to be more concerned with the protection and restoration of the environment through their tree farming activities. This probably could be attributed to the level of awareness of older farmers than younger ones.

In this light, the significant and direct relationship between knowledge level of households on tree-based systems and environmental protection motive has supported the above reasons.

5. Conclusions, Policy Implications and Recommendations

Conversion of degraded forest margins dominated by *Imperata* grassland into tree-based land use systems can provide significant improvements to a range of on-site and off-site benefits. Therefore, understanding smallholder farmers' tree growing objectives and the factors that influence such objectives are important considerations in designing rehabilitation plans for targeted development initiatives in the uplands.

Results of the study show that farmers invest in tree growing for both economic and non-economic reasons. Statistical evidence lends strong support to the hypothesis that smallholders' farm forestry is a multi-objective investment initiative. The underlying tree growing objectives identified were as follows: (i) monetary, economic security and asset motive; (2) recreation and aesthetic objective; and (3) environmental protection and restoration objective. Of these, monetary and other economic-related objectives accounted the most variations among farmers, and therefore were more preferred than non-economic objectives.

The following policy implications and recommendations are drawn based on the findings of the study:

1. There is a need to enhance the environmental fiscal reforms in smallholder tree farming initiatives to provide payments for the environmental and ecological services associated with the economic and non-economic motives of tree planting among smallholder farmers.
2. Knowing that smallholder farmers' recreation, environmental and restoration objectives are significantly influenced by their knowledge level on the economic and environmental benefits of tree-based systems, there is a need to continue the information dissemination activities through farmers' trainings and seminars.
3. Tree farming has been considered to provide more employment and economic opportunities for female than male farmers. A greater participation of women in tree farming investment decision-making would likely increase adoption of tree-based farming systems since they perceive more benefits than costs. It is therefore important to increase the role of women in tree growing investment projects as a platform to develop the marginal uplands.

References

Bandy, D.E.; D.P. Garrity and P.A. Sanchez. 1993. The Worldwide Problem of Slash-and-Burn Agriculture. Agroforestry Today 5(3): 2-6.

Carmines, E.G. and R.A. Zeller. 1979. Reliability and Validity Assessment. Sage University Paper Series on Quantitative Applications in the Social Sciences, 07-017. Newbury Park: Sage. 71p.

CMPDO (Claveria Municipal Planning and Development Office). 2000. Draft Comprehensive Land Use Plan, Planning Period: 2000-2010. Claveria, Misamis Oriental.

DENR (Department of Environment and Natural Resources). 1992. A Report on Philippine Environment and Development: Issues and Strategies. Quezon City: DENR.

Francisco, H.A. 1994. Upland soil resources of the Philippines: resource assessment and accounting for soil depreciation. Workshop Paper No. 6, Environmental and Natural Resource Accounting Project, Phase II, Final Workshop. March 16, 1994. INNOTECH, Quezon City.

Francisco, H.A. 1998. The Economics of Soil Conservation in Selected ASIALAND Management of Sloping Lands Network Sites in Asia. Bangkok, Thailand: IBSRAM. Issues in Sustainable Land Management no. 5.

Garrity, D.P. and P.C. Agustin. 1995. Historical Landuse Evolution in a Tropical Acid Upland Ecosystem. Agriculture, Ecosystems and Environment. 53:83-95.

Gouyon, A. 1992. Economic evaluation of technologies for smallholders: methodology and examples. Proceedings of the Symposium on Technology Transfer. The International Rubber Research and Development Board.

Hair, J.F. JR., R.E. Anderson, R.L. Tatham, and W.C. Black. 1998. Multivariate Data Analysis. 5th Edition. Printice-Hall, Inc. USA: New Jersey.

Houghton, R.A. 1996. Converting Terrestrial Ecosystems from Sources to Sinks of Carbon. Ambio. 25(4): 267-272.

Houghton, J.T., G.J. Jenkins and J.J. Ephraums (eds). 1990. Climate Change. The IPCC Scientific Assessment. Cambridge University Press, Cambridge.

Magcale-Macandog, D.M.; C. Artiaga; K. Menz; C. Predo; and E. Albacea. 1998. An Analysis of Shifting Cultivation Using the Trenbath Model. *In* Menz, K.M.; D.M. Macandog; and I.W. Rusastra (eds.). Improving Smallholder Farming Systems in *Imperata* Areas of Southeast Asia: Alternatives to Shifting Cultivation. ACIAR Monograph No. 52, 280 pp + XXXvi.

Mandac, A.M., M.P. Genesila, R.D. Magbanua. 1987. Multiple Cropping Systems in Northern Mindanao, Philippines. Philippine Journal of Crop Science. 12(2): 71-85.

Menz, K.M. and P.G. Grist. 1996. Changing fallow length in an Imperata/upland rice farming system. Imperata Project Paper 1996/6. Canberra, Australia: ANU.

Menz, K.M. and P.G. Grist. 1998. Impacts of Reductions in Fallow Length. *In* Menz, K.M.; D.M. Macandog; and I.W. Rusastra (eds). Improving Smallholder Farming Systems in *Imperata* Areas of Southeast Asia: Alternatives to Shifting Cultivation. ACIAR Monograph No. 52, 280 pp + XXXvi.

Mercado, A. JR. 1985. Basic Information About Claveria. Prepared for Distribution During the 3rd National Conference on Research in the Uplands Post-Conference Field Tour on September 9, 1995, held at ICRAF Research Site, Claveria, Misamis Oriental, Philippines.

Moura-Costa, P.H. 1996. Tropical forestry practices for carbon sequestration: a review and case study from Southeast Asia. Ambio. 25(4): 279-283.

Nelson, R.A. and R.A. Cramb. 1998. Economic Incentives for Farmers in the Philippine Uplands to Adopt Hedgerow Intercropping. Journal of Environmental Management. 54: 83-100.

Nelson, R.A.; R.A. Cramb; K. Menz; and M. Mamicpic. 1998. *Gliricidia*, Napier and Natural Vegetation Hedgerows. *In* Menz, K.M.; D.M. Macandog; and I.W. Rusastra (eds). Improving Smallholder Farming Systems in *Imperata* Areas of Southeast Asia: Alternatives to Shifting Cultivation. ACIAR Monograph No. 52, 280 pp + XXXvi.

Nowak, D.J. 1993. Atmospheric carbon reduction by urban trees. Journal of Environmental Management. 37: 207-217.

Romney, A.K., S.C. Weller and W.H. Batchelder. 1986. Culture as Consensus: A Theory of Culture and Informant Accuracy. American Anthropologist. 88:313-338.

Trexler, M.C. and C.M. Haugen. 1995. Keeping it green: evaluating tropical forestry strategies to slow global warming. World Resources Institute, Washington D.C. 52 pp.

World Bank. 1989. Philippine Environment and Natural Resource Management Study. A World Bank Country Study. Washington DC: World Bank.

Impact of Water Pollution on Rice Productivity in Vietnam

Huynh Viet Khai[1]* and Mitsuyasu Yabe[2]

Abstract: *To estimate the effect of water pollution on rice productivity, the study surveyed rice farmers in the polluted and the non-polluted regions. Difference in rice yield between two areas revealed the productivity loss of rice production due to water pollution was about 0.67 tons per hectare in a crop with a value of VND 2.7 million.*

Keywords: *Water pollution, rice productivity, Translog production function, Vietnam.*

1. Introduction

Vietnam has achieved the average GDP growth rate of 6.71 per year. The industrial sector has mainly contributed economic development in Vietnam, with annual growth of 12% during the period of 200-2009. In line with its industrialization and modernization policies, Vietnam has rapidly changed economic structure from agriculture base to industrial economy. The industrial and construction sector only contributed 26% of national GDP in 1986, but it rapidly increases to 40.3% in 2009.

Vietnamese has enjoyed a lot of benefits from economic development. Income, transportations, life condition have gradually improved and the percentage of the poor has progressively reduced. However, the consequence of rapid industrialization in Vietnam has a negative impact on agricultural activities, human and ecosystem due to its externalities like natural resources and soil degradation, air or water pollution and so on. The two biggest cities in Vietnam, namely Ha Noi and Ho Chi Minh, are ranked as the worst cities for dust pollution in Asia (The World Bank, 2008).

According to The World Bank report (2007), Ho Chi Minh - the biggest city in Vietnam - is ranked first on national pollution list. Large industries in terms of workers and number of firms release high pollution loads to air, land and water. For instance, footwear contributes 11% of pollution to air, 10% to land and 6% to water while 478 plastic products produce 10, 13 and 9% of pollution load to air, land and water respectively. However, the main pollution loads are not always from the large firms. The cement industry with only 12 factories and 0.5% of provincial workforce contributed 24% of air pollution load. Likewise, 160 paper factories recruiting only 0.8% of provincial workers produced 14% of water pollution load.

There are a number of empirical studies on agriculture related to environmental problems, such as soil degradation, wind and water erosion, but only a few studies have

[1] Laboratory of Environmental Life Economics, Division of International Agricultural Resource Economics and Business Administration, Department of Agricultural and Resource Economics, Graduate of Bioresource and Bioenvironmental Science, Faculty of Agriculture, Kyushu University, Japan
* Corresponding author (E-mail: hvkhai@ctu.edu.vn)
[2] Laboratory of Environmental Life Economics, Department of Agricultural and Resource Economics, Faculty of Agriculture, Kyushu University, Japan.

examined the impact of industrial pollution on agriculture and other sectors. Lindhjem *et al.* (2007) for instance evaluated the reduced crop quality and quantity on polluted irrigation water. The study estimated a yield loss of RMB 360 per mu, of which the quantity loss is RMB 285, and the quality loss of RMB 75 per mu. The World Bank (2007) estimated the health and non-health losses caused by air and water pollution in China. The report calculated the economic losses from crop damage caused by water pollution, which stem from crop reductions in both quantity (reduced yield) and quality (excess pollutants and substandard nutritional value). The report estimated the economic cost of wastewater irrigation in China was about 7 billion RMB annually for the four major crops (wheat, corn, rice, and vegetables).

In the recent years, there are some studies related to industrial pollution that have been made in Vietnam. Le Quan Thong (2004) discovered that water pollution has been a serious problem in the big industrial parks of Ho Chi Minh City, and Binh Duong, Dong Nai and Ba Ria-Vung Tau Provinces. The study identified financial constraints and limited land space were the reason why many small and medium-sized enterprises could not afford to invest in wastewater treatment systems. Pham Thai Hung *et al.* (2008) studied the effects of trade liberalization on environment vis-à-vis the increasing of pollution level in Vietnam, using secondary data from the Viet Enterprise Survey (VES) of 2002 and the World Bank's Industrial Pollution Projection System (IPPS). The result revealed that trade liberalization makes the quality of environment degraded and more polluted. Vietnamese has gradually recognized the importance of environmental protection. However, those of studies in Vietnam have nothing related to agricultural loss.

The lack of information on the costs of pollution prompted the national and local authorities in Vietnam not to pay much attention to pollution control. Thus, the study will make attempt to estimate the yield loss of rice due to water pollution. It will be possibly useful for those with responsibilities to enforce existing water pollution regulations, for example, TCVN 5945 on water pollution standards, or Decree 67 on wastewater pollution charges and also provide good information to authorities from Natural Resource and Environment department and industrial zones for managing water pollution problems. The study will also be the very useful in providing important information for analyzing the Cost Benefit Analysis (CBA) for the treated projects in industrial zones in Vietnam in the future. The study also helps us to understand or recognize the failure of the current environmental policies in Vietnam.

2. Methodology

2.1. Study Site Description

In the Mekong River Delta, there are about 33 industrial parks, which constituted 9.5% of total industrial zones of the country. Almost all of them have no wastewater treatment system. The industrial parks in Can Tho city have released the biggest pollution loads, and been ranked in the list of Top 10 most polluted provinces in Vietnam (Table 1). Can Tho city also is one of the biggest rice producers in the Mekong River Delta. Because of these reasons, Can Tho was selected as the study site.

Table 1. Top 10 most polluted provinces in Vietnam

Province	Air index	Land index	Water index	Overall
Ho Chi Minh	1	1	1	1
Hanoi	5	2	2	2
Hai Phong	2	6	4	3
Binh Duong	6	3	3	4
Dong Nai	4	4	5	5
Thai Nguyen	3	5	7	6
Phu Tho	7	7	6	7
Da Nang	10	9	8	8
Ba Ria Vung Tau	9	8	10	9
Can Tho	8	10	9	10

Source: The report of World Back, 2007

There are 6 industrial parks in Can Tho city (Table 2). The main products of Can Tho industrial zones are agricultural and fishery processing, clothes and consumer goods. Almost all industrial zones and industrial corporations located in residents' regions have not installed wastewater treatment systems. The management of toxic waste as well as water pollution is not paid much attention by local authorities and firms. Tra Noc 1 (built in 1995) and Tra Noc 2 (built in 1999) are just only accepted by the Ministry of Resource and Environment while Thot Not is discussed and considered by Can Tho authorities to evaluate the impact of environmental pollution (The report of Resource and Environment department of Can Tho city, 2008). The consequence is that Tra Noc 1 and Tra Noc 2 have directly released thousands m^3 of various kind of waste into the river (Bui Canh Tien, 2009).

Table 2. The industrial zones in Can Tho city

Zones	Size (ha)	Main activities	Water treatments
Tra Noc 1	135	Processing, electron, clothes	No a
Tra Noc 2	165	Machinery	No a
Hung Phu 1	262	Harbor, Store	No
Hung Phu 2	212	Machinery	No
Hong Bang	38,2	Consumer goods	No a
Thot Not	150	Processing, clothes, shoes	No a

a The available decision and acceptation of local authorities to evaluate the impact of environmental pollution.

Source: The report of Resource and Environment department of Can Tho city, 2008)

2.2. Data Collection

The study region is in or around Tra Noc 1 and Tra Noc 2 industrial zones, two of the most pollutants in Can Tho city. People living in and around this area have suffered damages in terms of losses to crops, cattle and agricultural equipment such as pump sets, contamination of drinking water, diseases and deaths due to water pollution.

Farmers in two areas with the consideration of the same social or natural conditions and fertile soils are randomly selected for interview. The selections of the polluted and non-polluted area are based on their distance from industrial zones, and on the recommendation or suggestion of local authorities and farmers. Some villages in Phuoc Thoi district represent the heavily polluted villages mainly due to wastewater from the Tra Noc 1 and 2 industrial zones. The villages in Thoi An district have the same social and natural condition with Phuoc Thoi and far from industrial zones represent the non-polluted area (see Figure 1). In selected areas, 364 rice farmers were interviewed from February to March 2010, consisting of 214 farmers in the polluted and 150 farmers in the non-polluted area. Detailed household level information related to production costs, income and the social and economic characteristics of farmers, the damages and losses due to water pollution were collected.

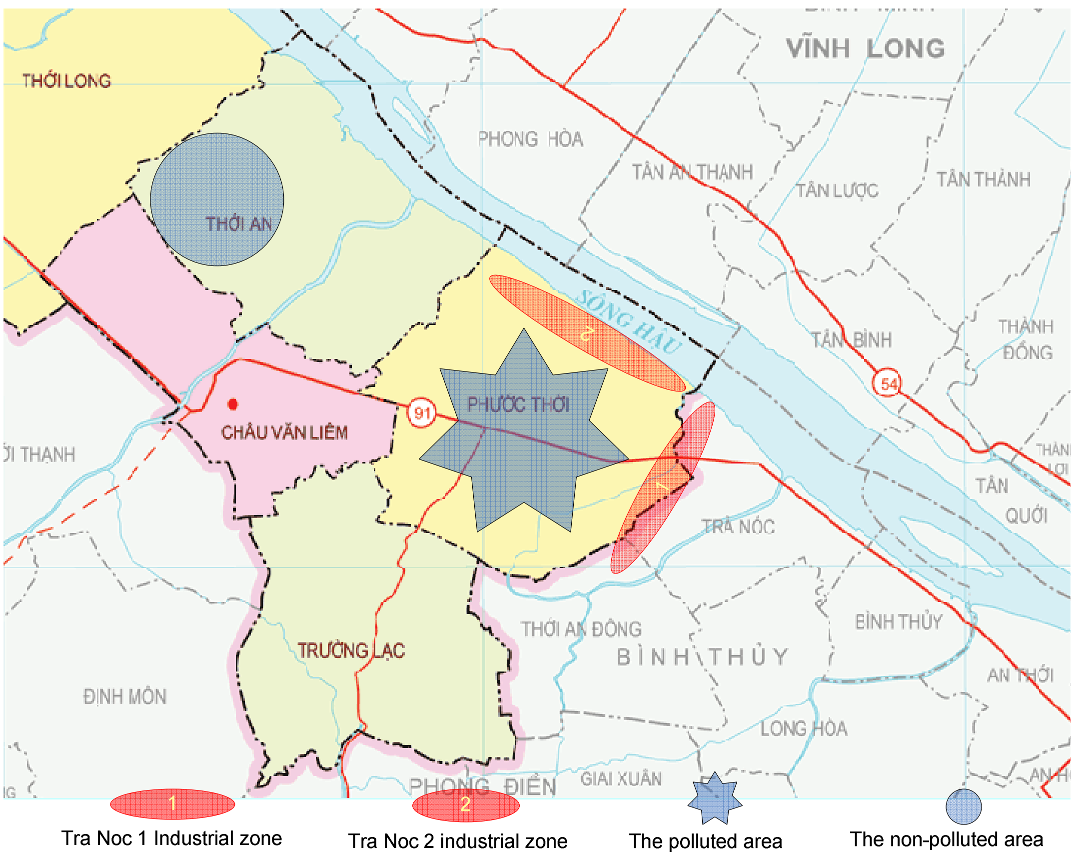


Figure 1. Map showing study site.

Table 3. Water quality of the polluted and non-polluted area

	TSS (mg/l)	COD (mg/l)	NH3-N (mg/l)
The polluted area [(1)]			
- Sewer mouth	*145*	*720*	*13.29*
- Primary affected water source	*50*	*50*	*1.23*
- Secondary affected water source	*60*	*48*	*0.63*
The non-polluted area [(2)]	**22**	**5.1**	**0.16**
Limitation value (TCVN5942,1995)			
- Class A [(3)]	*20*	*10*	*0.05*
- Class B [(4)]	*80*	*35*	*1*

Source: (1) Measured on January 17th, 2007 (Bui Thi Nga, 2008)
(2) Measured on January 27th, 2007 (Vo Thi Lang, 2009)
***(3)* Values in the class A are applied to the surface water using for source of domestic water supply with appropriate treatments.**
(4) Values in the class B are applied to the surface water using for the purposes other than domestic water supply. Quality criteria of water for aquatic life are specified in a separate standard.

Table 3 shows the water quality index of the polluted and non-polluted area.The Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. High concentrations of TSS can block light from reaching submerged vegetation, slowing down photosynthesis. This causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die (World Bank, 2007). Chemical Oxygen Demand (COD) is the amount oxygen used during the oxidation of organic matter and inorganic chemicals such as ammonia and nitrite (NH3-N). The high amount of COD performs the releases of big pollution loads to the environment.

In the polluted area, the levels of SS, COD and NH3-H in the sewer mouth, primary affected water source and secondary affected water source regions mostly are much higher than standard value of TCVN5942-1995 (Water Quality, Surface Water Standards), revealing the selected pollution site is heavily polluted. The levels of TSS, COD and NH3-N in the sewer mouth region are nearly double, over 20 and 13 times higher than the standard value of class B, respectively.

The differences in water quality index between the polluted and non-polluted areas indicate that the water quality in the non-polluted area is significantly better than the water in the polluted area. However, the amount of TSS and NH3-N in the non-polluted is little higher than the standard level of class A. Possible explanation is that the water in this region might be impacted from non-point source pollutants mainly produced by agricultural activities like the overuse of fertilizer, herbicide and pesticide and so on.

2.3. Production Function Approach

The principle of production function approach is that industrial activities possibly have a negative impact on the outputs, cost and profit of producers through the effect of environment. Environment affects goods or services existing in the market through the value change of their outputs, for instance, the reduced value of fish caught because of river pollution. Production function approach is often used to estimate the effect of environment change on soil erosion, deforestation, fisheries, the impact of air and water pollution on agriculture and so on (Bateman *et al.* 2003)

A literature search on the production function approach in rice production Vietnam is conducted to make sure that relevant variables will be included in the farm survey questionnaire and to examine the suitability of existing rice production models for the research. There are a number of studies related to rice production in Vietnam. Kompass (2004) and Linh Hoang Vu (2007) used stochastic production frontier to estimate technical efficiency of rice production in Vietnam. Thang Nam Do (2007) used production function approach with flood duration and relative location of upstream and downstream farmers variables to estimate the cost of changing wetland management, representing the reduced income of rice production in the Mekong River Delta. The loss of rice productivity was estimated based on the differences in rice yield between Upper and lowering of the Tram Chim park dyke. The results showed that the rice productivity in the lowering of park dyke decreased 0.06 tons per hectare per annum, which led to the profit loss of VND 0.07 million per hectare per annum. These three studies used the Cobb-Douglas functional form of rice production function approach. However in this study the Translog functional form was used, and does test for checking the existence of Cobb-Douglass. The model takes the basic form:

$$Y = f(L, K, I, Z, E, F) \qquad (1)$$

where Y is the rice yield of a farmer in the studied year (tones/ha), L is the number of labors for rice cultivation (man-days/ha), K is capital input (VND/ha), I is a vector of material inputs as seeds (kg/ha), fertilizers (kg/ha), herbicide (ml/ha) and pesticides (ml/ha), Z is a vector of social-economic characteristics of farmers, and E is vector of farming conditions and environmental factors, and F is the relative location of farms (polluted site = 1, non-polluted site = 0)

The reduced yield of rice is defined as the difference in the average rice yield between the non-polluted and polluted site. It will be estimated by following equation:

$$\Delta Y = f(\bar{L}, \bar{K}, \bar{I}, \bar{Z}, \bar{E}, F = 0) - f(\bar{L}, \bar{K}, \bar{I}, \bar{Z}, \bar{E}, F = 1) \qquad (3)$$

where ΔY is the average yield loss caused by water pollution (kg/ha); $\bar{L}, \bar{K}, \bar{I}, \bar{Z}, \bar{E}$ are the average of labor, capital input, material inputs, social-economic characteristics, and farming conditions and environmental factors, respectively.

As mentioned earlier, a translog functional form is used in the study. The production functional form in the polluted and non-polluted areas is written as followed (Tim Coelli D.S.Prasada Rao and George E.Battese 2005):

$$\ln(Y) = \alpha_0 + \alpha_1 \ln(L) + \alpha_2 \ln(K) + \alpha_3 \ln(I) + \frac{1}{2}\alpha_{11}\left(\ln(L)\right)^2 + \alpha_{12}\ln(L)\ln(K) + \alpha_{13}\ln(L)\ln(I) + \\ + \frac{1}{2}\alpha_{22}\left(\ln(K)\right)^2 + \alpha_{23}\ln(K)\ln(I) + \frac{1}{2}\alpha_{33}\left(\ln(I)\right)^2 + \sum_{k=1}^{5}\beta_k Z_k + \sum_{h=1}^{4}\delta_h E_h + \gamma F \quad (4)$$

where *Y, L, K, I, F* are the same as in the above equations and Z_1, Z_2, Z_3, Z_4 are the variables of the gender (1 = male, 0 = female), the age (years), the number of school year (years), attending trainings (1 = Yes, 0 = No) of rice households, and E_1, E_2, E_3, E_4 are the variables of serious diseases happening during the study year (1 = Yes, 0 = No), rice monoculture (1 = yes, 0 = No), soil quality (1 = fertile soil, 0 = other soils), off-farm income ratio.

Some restrictions are used to check the constant returns to scale:

$$\begin{aligned} &\alpha_1 + \alpha_2 + \alpha_3 = 1 \\ &\alpha_{11} + \alpha_{12} + \alpha_{13} = 0 \\ &\alpha_{12} + \alpha_{22} + \alpha_{23} = 0 \\ &\alpha_{13} + \alpha_{23} + \alpha_{33} = 0 \end{aligned} \quad (5)$$

Then, the following restriction is applied to test the existence of Cobb-Douglass function:

$$\alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{22} = \alpha_{23} = \alpha_{33} = 0 \quad (6)$$

Table 4. Description of variables in rice production function

Variable	Description	Unit
Rice	Total yield per hectare	ton/hectare
Seed	Total amount of seed used	Kg/hectare
Herbicide	Total amount of herbicides used	Equivalent unit of ml/hectare
Fertilizer	Total amount of fertilizer used	Kg/hectare
Pesticide	Total amount of pesticide used	Equivalent unit of ml/hectare
Labor	The number of man-days for rice production	day/hectare
Capital	The money of machines and services at all stages of rice production	VND/hectare
Gender	The gender of respondents	1 = male , 0 = female
Age	The age of respondents	Years
Education	The number of school year of respondents	Years
Training	Respondents attending trainings	1= Yes, 0 = No
Mono	Rice monoculture	1= Yes, 0 = No
Diseases	Diseases happening during the study year	1= Yes, 0 = No
Off-farm ratio	The ratio of off-farm income	
Soil	Soil quality	1 = fertile soil, 0 = other soils

Table 6 shows the definitions of variables in rice production function. The amount of herbicide and pesticide are measured by equivalent unit of ml per hectare per crop based on experts' recommendations, because it is difficult to separate the mixed amount of herbicide and pesticide in water and flour.

Table 5. Descriptive Statistics of Rice Production per hectare per crop

Variables	Non-polluted	Polluted	t-ratio
Rice	5.88	4.99	-7.31***
Seed	224.41	206.42	-2.37**
Herbicide	1043.34	1170.48	1.33
Fertilizer	475.87	463.76	-0.53
Pesticide	7725.80	7022.68	-1.24
Labor	29.03	32.95	1.39
Capital	3283.02	3436.20	1.06
Gender	0.91	0.93	0.76
Age	48.04	48.99	0.81
Education	6.33	6.07	-0.87
Training	0.49	0.35	-2.72***
Mono	0.60	0.58	-0.39
Diseases	0.40	0.42	-0.39
Off-farm income share	0.20	0.37	4.72***
Soil	0.63	0.75	2.35**

Notes: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively
Source: Own estimates; data appendix available from authors.

Table 5 shows the descriptive statistics of main variables in rice production function between polluted and non-polluted area. Although soil quality in the non-polluted is significantly worse than in the polluted region at the level of 5 percent, rice productivity in non-polluted is significantly higher than one in polluted area at the level of 1 percent, likely existing the negative effects of water pollution on rice cultivation. The difference of the off-farm income ratio in two areas shows that farmers might recognize the reduced profit of rice cultivation in the polluted soil. Then, they have tendency to find jobs as workers in industrial parks near their homes. This could help them earn more income other than rice cultivation.

Other factors have the same values in the two regions, excepting *Training* variable. The result also shows that about 60 percent of farmers have an age of 48 year old, grow rice monoculture and with more than 6 years average education. . The result reveals that Vietnamese farmers are mostly the old people with low education.

3. Results and Discussions

Table 6. The OLS regression of rice production function in the whole area

Variables	Coefficient	Standard Error
Ln(Seed)	0.696	0.799
Ln(Herbicide)	-0.123	0.154
Ln(Fertilizer)	0.465	0.555
Ln(Pesticide)	-0.157	0.265
Ln(Labor)	0.851**	0.333
Ln(Capital)	0.572	0.439
*½ Ln(Seed)*Ln(Seed)*	0.532***	0.196
*½ Ln(Herbicide)*Ln(Herbicide)*	0.000	0.005
*½ Ln(Fertilizer)*Ln(Fertilizer)*	0.037	0.032
*½ Ln(Pesticide)*Ln(Pesticide)*	-0.011	0.017
*½ Ln(Labor)*Ln(Labor)*	0.059*	0.033
*½ Ln(Capital)*Ln(Capital)*	0.075	0.070
*Ln(Seed)*Ln(Herbicide)*	0.014	0.027
*Ln(Seed)*Ln(Fertilizer)*	-0.132	0.098
*Ln(Seed)*Ln(Pesticide)*	-0.057	0.052
*Ln(Seed)*Ln(Labor)*	-0.105*	0.058
*Ln(Seed)*Ln(Capital)*	-0.216*	0.116
*Ln(Herbicide)*Ln(Fertilizer)*	-0.025	0.035
*Ln(Herbicide)*Ln(Pesticide)*	0.007	0.010
*Ln(Herbicide)*Ln(Labor)*	0.021	0.014
*Ln(Herbicide)*Ln(Capital)*	0.008	0.023
*Ln(Fertilizer)*Ln(Pesticide)*	0.060	0.040
*Ln(Fertilizer)*Ln(Labor)*	-0.026	0.046
*Ln(Fertilizer)*Ln(Capital)*	-0.022	0.084
*Ln(Pesticide)*Ln(Labor)*	-0.031	0.022
*Ln(Pesticide)*Ln(Capital)*	0.029	0.042
*Ln(Labor)*Ln(Capital)*	-0.023	0.040
Gender	0.098***	0.034
Age	-0.002**	0.001
Education	0.004	0.003
Training	0.039**	0.019
Disease	-0.012	0.018
Mono	0.016	0.022
Soil	0.031	0.019
Off-farm income ratio	-0.054*	0.028
Polluted	-0.127***	0.019
Constant	-5.615**	2.482
R-square	0.64	
Included observation	364	

Notes: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively
Source: Own estimates; data appendix available from authors.

Table 6 shows the OLS result of rice production function in Translog form. The variables estimated in the model are statistically significant at 1 percent level. The estimated R-square is equal to 0.64, revealing the 64 percent change of rice yield possibly explained by independent variables in the model.

The study also examines the null hypothesis that there is a proportional output change when inputs in the model are varied or farms produce rice with constant returns to scale. The restricted least squares regression with the null hypothesis of constant returns to scale is estimated. The computed F statistic is 37.09, which is more than the critical value F (7, 327) of 3.58 at 0.1 percent level of significance [1)]. Thus, the null hypothesis is rejected and the study concluded that technology does not exhibit constant returns to scale.

The second test was applied to check the Cobb-Douglass formal existence of production function. With the null hypothesis of jointed parameters in (6) equal to 0, the restricted function is estimated. The computed F statistic of 1.94 is more than the critical F(21,327) of 1.91 at 1 percent level of significant [1)]. The null hypothesis is rejected and the Translog functional form is suitably applied for the data of rice production in the study.

Table 6 shows that the coefficient of *Polluted* variable is significantly negative at 1 percent level, revealing that rice productivity in the polluted is lower than in the non-polluted area. The other variables of *Labor, Gender* and *Training* are significantly positive. The result also indicates that male farmers were able to produce more yields compared to farmers with the final decision by female. This reveals the skill and technology level of male households is higher. More labor investments also make rice cultivation more productivity. Short training courses such as 3-reduction and 3-increase, IMP program, guideline of applying new technologies and so on normally given by local extension services partly contribute an increase in rice yield.

Moreover, the negative coefficient of *Age* variable is statistically significant at 10 percent level. The older farmers the less productivity they obtain. Possible explanation is that farmers' age is averagely 48 years in the sample. At this age, decrease in health makes farmers cultivate rice less efficiently. In addition, the result shows the sign of off-farm income ratio variable is significantly negative at 5 percent level. Farmers who earn more off-farm income produce less rice. Through the farmers' survey, we find out that when rice production is not profitable anymore, farmers in the polluted region have tendency to sell their rice lands for buildings or use rice lands for rent (farmers from other regions rent their lands). Local farmers try to find jobs in industrial parks that help them earn more compared to rice production. The study also discovers that water pollution makes farmers change their behavior of rice cultivation and crop intensification. Before their source of income came mainly from rice production with three rice crops per year. At present, they do rice farming as part-time jobs. They grow one or two crops per year and harvest rice just enough for home consumption. These outcomes can be associated with the negative impact of off-farm income on rice productivity.

The reduced productivity of rice due to wastewater irrigation is calculated based on findings from Table 6. The estimated yield in the non-polluted area is about 5.61 tons and around 4.94 tons for the polluted region. The equation (3) is used to calculate the loss of rice yield due to polluted water irrigation by subtracting the yield in the polluted region from yield in the non-polluted region. The estimated result is about 0.67 tons per hectare per crop (5.61 tons – 4.94 tons). With the assumption of rice price of VND 4 million per ton, the reduced value is estimated around VND 2.7 million per hectare per crop.

4. Conclusions

The study surveyed rice farmers in two areas with the assumptions of the same natural condition and social characteristics. One is considered as the polluted area near and directly receiving wastewater from industrial parks, while the other is assumed to be non-polluted area far from and having no effect of industrial pollutants. The productivity loss of rice production caused by water pollution was estimated by the difference in rice yield between the two regions. The results showed that the yield loss of rice was about 0.67 tons per hectare per crop, equal to the loss value of VND 2.7 million. The study also discovered that farmers in the polluted site do nothing, but use water irrigation in the highest level of water tide to reduce the effect of wastewater on rice production. They thought the water at the high tide level looked less polluted than water in other time although it was always heavily polluted near industrial parks.

According to The World Bank (2007), the development of rice roots and seedlings could be influenced by using wastewater for irrigation. Polluted water irrigation causes the reduction of height, leaf area and dry matter. Decrease in leaf surface area leads to the reduction of photosynthesis. These facts have directly impact on rice production. In other words, the impacts of polluted water on rice productivity mainly reduce the number of ears unit area, number of seed per ear and seed weight. The study estimated water pollution caused yield reduction about 12 percent. This result is nearly equal to the reduced yield of 10 percent in the sewage-irrigated area in comparison with clear water-irrigated areas estimated by Bai Ying et al. (1988), but much lower than the rice reduced productivity of 20% calculated by Song (2004) cited by Lindhjem (2007) and 30% by Chang et al. (2001).

The effect of water pollution on agricultural production includes decrease in crop quantity, product quality, crops that have higher pollution level compared to the standard of allowable pollution levels and deterioration of agro-ecological environments like soil pollution of farmland, destruction of soil structure and groups of soil microorganisms. The study only estimated the quantity reduction of rice production due to water pollution. In-depth study should be done to calculate the total loss of agricultural crops in Vietnam.

In addition, the study also found out the occurrence of skin diseases on farmers working in polluted region. For instance, farmer in the polluted area reported that he suffered from skin disease for 5 days per year, which cost him VND 500.00 for the treatment. The diseases also caused the loss of 2.5 workdays, equivalently to VND 250.000. Therefore, the calculation of reduced value of rice in the future study will be underestimated if indirect costs like the health cost suffered by farmers who have to directly contact with polluted water during farm activities are neglected.

Acknowledgment

The authors would like to express our sincere gratitude to Dr. Benoit Laplante, a long-standing resource person with EEPSEA and Dr Herminia Francisco, a director of EEPSEA, for their valuable comments and suggestions in shaping the structure of the study and data analyses. My warmest thanks go to EESEA for sponsoring the study. The draft article read by Mr. Joshep Arbiol in our laboratory and assistance of colleagues in Can Tho University in data collection are appreciated.

Notes

1) Calculated by the formula $F = \frac{(SSE_R - SSE_U)/J}{SSE_U/(I-K)}$, where SSE_R and SSE_U are the restricted and unrestricted sums of squared residuals and J is the number of restrictions

References

Bai,Y.e.al. Pollution of irrigation water and its effects, Beijing. 1988. Beijing Agriculture University Press.

Ref Type: Report

Bateman et al. 2003. *Economic Valuation with Stated Preference Techniques.*Edward Elgar Publishing, London.

Bui Canh Tuyen. Strategy of Vietnam towards addressing Environment and Climate risks. 2010.

Ref Type: Slide

Bui Thi Nga, Nguen Thanh Giao, and Pham Viet Nu 2008. "Effects of waste water from Tra Noc industrial zone on adjacent rivers in Can Tho city." *Scientific journal of Can Tho University* 9(2):194-201.

Chang Yongguan and et al. 2001. "The environmental cost of water pollution in Chongqing, China." *Environment and Development Economics* 6:313-33.

Le Quang Thong and Nguyen Anh Ngoc. Incentives for Wastewater Management in Industrial Estates in Vietnam. 2004. the Economy and Environment Program for Southeast Asia (EEPSEA).

Ref Type: Report

Lindhjem H.et al. 2007. "Emvironmental economic impact assessment in China: Problems and Prospects." *Environmnetal Impact Assessment Review* 27(1):1-25.

Linh Hoang Vu 2007. "Efficiency of Rice Farming Households in Vietnam: A DEA with Bootstrap and Stochastic Frontier Application." *University of Minnessota, Minesota, USA*.

Pham Thai Hung et al. The Impact of Trade Liberalization on Industrial Pollution: Empirical Evidence from Vietnam. 2008. the Economy and Environment Program for Southeast Asia (EEPSEA).

Ref Type: Report

Quang M.Nguyen 2001. "An Evaluation of the Chemical Pollution in Vietnam." Unpublished.

Reddy,V.R. and B.Behera 2006. "Impact of water pollution on rural communities: An economic analysis." *Ecological Economics* 58(3):520-37.

Thang Nam Do and Jeff Bennett. Would wet biodiversity conservation improve social welfare? A case study in Vietnam's Mekong River Delta. International Conference on Sustainable Development: Challanges and Opportunities for GMS . 2007.

Ref Type: Conference Proceeding

Tim Coelli D.S.Prasada Rao and George E.Battese 2005. *An introduction to efficiency and productivity analysis.* New York: Springer Science.

Tom Kompas 2004. "Market reform, productivity and efficiency in Vietnamese rice production." *International and Development Economics, Australian National University working Papers* 4(4):587-623.

Vo thi Lang, Ky Quang Vinh, and Ngo Thi Thanh Truc. Environmental Consequences of and Pollution Control Options for Pond "Tra" Fish Production in Thotnot District, Can Tho city, Vietnam. 2009. The Economy and Environment Program for Southeast Asia (EEPSEA).

Ref Type: Report

_______ 2007. *Cost of pollution in China - Economic estimates of physical damages.*The World Bank.

The willingness to pay of industrial water users for reclaimed water in Taiwan

Yawen Chiueh[1]*, Hsiao-Hua Chen[2], Chung- Feng Ding[3], Hsiu-Chen Lu[4], Pei-Chun Hsieh[4]

Abstract

The industry of wastewater reclamation is young and only limited on the deployment of water reuse system inside the factories in Taiwan. The future developments of reclaiming the effluents from domestic and industrial wastewater treatment plants (WWTPs) are expected because of the serious shortage of available water resources in Taiwan. The Wastewater Reclamation and Reuse Industry can be categorized by “produce / supply model” and “produce / use model”. This study focuses on the “produce / supply model” which considers the reclamation of industrial and domestic wastewater from the WWTPs, and the user (demand side) will be the industrial factories in the future. This study uses the contingent valuation method and contingent behavior to evaluate the demand for the reclaimed water of the produce / supply model. The demand investigations on 374 factories in 7 local industrial parks in Taiwan are conducted. The reclaimed water demand is 131,000 CMD and the willingness to pay is 13.97N.T./ton.

keyword：reclaimed water, contingent valuation method, contingent behavior, produce / supply model

---

1 Associate professor, Department of Environmental and Cultural Resources, National Hsinchu University of Education, Taiwan. EMAIL：yawen.chiueh@gmail.com

2 Senior researcher and Vice president, Environment and Development Foundation, Hsinchu, Taiwan .

3 Associate Researcher, Water Problems Enterprise Information & Incubation Center Tainan Hydraulics Laboratory, Water Resources Agency, Ministry of Economic Affairs/ National Cheng Kung University

4 Engineer, Water Problems Enterprise Information & Incubation Center Tainan Hydraulics Laboratory, Water Resources Agency, Ministry of Economic Affairs/ National Cheng Kung University

1. Introduction

Water resource in Taiwan is mainly delivered through diversion from river, regulation of reservoir and groundwater extraction. Diversion from river is dependent on hydrological conditions on yearly bases. Reservoir regulation is unpredictable and subject to actual conditions of the watershed, and moreover, building a reservoir involves huge funding and takes a long time in addition to frequent confrontation of questioning and protests of environmental groups. As for groundwater extraction, land subsidence resulting from excessive groundwater extraction leads to national land conservation issues. Considering natural restrictions and environmental policies, wastewater reclamation has become an important topic when the government seeks for new water sources. Aiming to resolve the supply of water resource, the government is progressively promoting the wastewater reclamation industry and exploiting the corresponding market. With provision of statutes that favor the development of wastewater reclamation industry as well as financial setup that supports relevant technologies, the government expects to counsel the private sector to participate in establishing a wastewater reclamation industry that conforms to the trend of green ecology

In 2008, Water Resources Agency of MOEA finalized the definition of the term "Reclaimed Water" as "the product of a wastewater treatment plant by treating the livelihood wastewater and industrial wastewater to an acceptable standard of water quality". The Agency defines that Reclaimed Water shall be employed without contacting with the human body, and that applications of Reclaimed Water shall be restricted to industrial uses such as industrial process water, cooling tower make-up water, and cleaning water within industrial areas, agricultural reuse, urban landscaping, aquifer recharge, and maintenance of river carrying capacity. Based on this definition, "Wastewater Reclamation" shall mean the process in which wastewater (sewage) is treated by a Wastewater Recycling Plant (WWRP) to a specific quality level of a particular usage to achieve reuse of the water resource. Quality requirements of the Reuse Water can be grouped into three categories based on target uses: water for miscellaneous use, cooling water, and water for advanced use. "Water for miscellaneous use" denotes water used for urban landscaping, firefighting, toilet flushing, and street washing. "Water for advanced use" means the reclaimed water that meets minimum standards of city water used in industrial processes for washing and cleaning purposes, which may include the cooling water in the objective aspect. "Wastewater Reclamation Industry" shall denote the suppliers who provide services and equipment on Wastewater Reclamation technologies, including engineering consultants (for design and planning), construction contractors, operation and maintenance contractors, equipment agents and distributors, and equipment manufacturers.

Wastewater Reclamation can be divided into "produce/supply model" and "produce/use model". The Wastewater Reclamation Industry in Taiwan is closely linked with these two models as depicted below: 1. Existing Produce/Use Models include 4 categories: (1) Wastewater reclamation within a building: used for toilet flushing, plant watering, floor washing, landscaping and miscellaneous uses. (2) Internal recycling of single plant wastewater: for in-plant landscaping and watering, livelihood uses, industrial process uses, cooling tower make-up, etc. (3) In-plant reclamation of effluent of urban sewage treatment plant: for in-plant washing, landscaping watering, toilet flushing and other livelihood miscellaneous use. (4) In-plant reclamation of effluent of industrial park sewage treatment plant: for in-plant washing, landscaping watering, and toilet flushing and other livelihood miscellaneous use. 2. Produce/Use Model includes that are yet to be formed include 3 categories: (1) Reclamation of single plant wastewater for external use: for landscaping watering, toilet flushing and other livelihood miscellaneous use of other factories, as well as for industrial process use and cooling tower use of other factories. (2) Reclamation of effluent of urban sewage treatment plant for external use: for urban park watering, street landscaping, street washing, school toilet flushing, cleaning, golf course lawn watering and other livelihood miscellaneous use; for supplying to industrial factories as process water and cooling tower make-up water; for groundwater recharge; and for agricultural irrigation. (3) Reclamation of effluent of industrial park sewage treatment plant for external use: supply to factories within industrial part for landscaping watering, toilet flushing and other livelihood miscellaneous uses; for supplying to factories within industrial park as process water and cooling tower make-up water.

Taiwan has had a wastewater reclamation industry of the produce/use model instead of the produce/supply model. The main reason is that the government has encouraged the industry to achieve "process recycle ratio" and "total plant recycle ratio" for more than 10 years, and there have been operators in Taiwan engaged in wastewater reclamation plants of "produce/use" model. However, wastewater reclamation plants of the "produce/supply" model still remain in the Model Plant stage and require successive fostering. Even in advanced countries such as EU, USA or Japan, there had been a number of barriers hindering the promotion of wastewater (sewage) reclamation; one of them is the dominant insufficiency of user confidence over quality and safety of the reclaimed water. In Taiwan, except adopting the produce/use model - in which factories who promote water saving within the industrial park reclaim their own wastewater for reuse, the environmental assessment requires that wastewater or sewerage within a building to be reclaimed by the building, or a wastewater/sewage treatment plant reclaims a portion of its own effluent for in-plant miscellaneous use - no other industrial development or application reference has been seen. Furthermore, affected by the lacking of experience and the rather low water price, the willingness to use reclaimed wastewater has been fairly low.

The Hydraulic Planning and Experimental Institute made a preliminarily research in 2009 and found that potential candidates for the use of reclaimed water include: 1. Water for secondary livelihood use: using effluent of urban wastewater/sewage treatment plant for watering nearby golf courses, to enhance flexibility of the local supply of water resources. 2. Water for agricultural use: treating effluent from the urban wastewater/sewage treatment plant to meet the standard of “water quality for irrigation” and using the reclaimed water for agricultural irrigation in areas having a water shortage. 3. Water for conservation: using water reclaimed from urban wastewater/sewage treatment plants for groundwater recharge, for artificial recharge of disaster prevention purposes, for agricultural use in substitution for the groundwater which would have originally been extracted, so as to alleviate groundwater extraction. And 4. Water for industrial use. Organizations that may increase water consumption in the future include: Hsinchu Science Park Yilan Base, Taoyuan Aviation City, Taipower Letzer Industrial Park Power Plant, Taipei Harbor Power Plant, Expansion Project of Dragon Steel Corporation, Middle Taiwan Science Park Taichung Base and Houli Base, Taichung Harbor Proprietary Areas (including power plant, petrochemical and industrial areas), Hsinchu Science Park Phase IV Tongluo Base, Yunlin Offshore Fundamental Industrial Park, Taiwan Petroleum Corporation Third Naphtha Cracker Renovation Project, Tainan County Great Hsinyin Industrial Park Development Project, Southern Taiwan Science Park Phase II, Development Project of Southern Taiwan Science Park LCD TV District (Tree Valley Park), Tinnan Industrial Park, and China Steel Corporation. The study carries out questionnaire interview with industrial water users to comprehend their willingness towards paying for the reclaimed water as well as their methods to use the same.

2. Method

2.1. The Theoretical Model

The study employs Contingent Valuation Method (CVM) to analyze the "willingness to pay (WTP)" of future industrial water users for using reclaimed water. The CVM method surveys user valuation over non-existing transactions of goods or services in the market by way of a direct questionnaire designed basing on hypothetic conditions in the market, therefore is a valuation method over non-market resources. The major feature of the CVM model is the forward-looking (ex ante) decision which evaluates a future event in advance. The price and quality level of the reclaimed water supply mechanism are presumed by the study without actually putting into operation; they are preliminary assumptions of the future supply mechanism of the reclaimed water which may be applicable to the existing factories of the industrial and science parks, for further understanding the WTP level of users regarding water price and the quality level.

The major difference of the CVM approach contrasting with a direct valuation approach is that CVM is specific in combining the survey practice with theories. Popular use of the CVM approach began in 1970's when the Forest Act of UK and the presidential directive #12291 were promulgated; a number of researches were seen conducted with the CVM approach over economic benefits of natural resources. During the Exxon tanker oil spoil incident in 1989, the federal court of USA ordered compensation to be paid by Exxon appraised with the CVM approach, enhancing the authenticity of the same. By 1993, since the US government extensively used CVM to make public policies that concern natural resources, the National Oceanic and Atmospheric Administration (NOAA) therefore promulgated guidelines on the use of the CVM approach, regulating the use of Contingent Valuation Surveys. Research papers show that CVM is applicable to offering a rational valuation over public goods or environmental goods [Smith, 1993]. Mitchell & Carson, [1989] and Hutchinson, et al. [1995] also pointed out that as long as the questionnaire is duly designed, CVM is a highly credible means for price evaluation.

The CVM appraisal can be conducted with a Random Utility Model [Hanemann, 1984] or an Expenditure Function [Cameron, 1988]. However, Cameron points out that the dichotomous choice data of Random Utility Model [Hanemann, 1984] is ordered, and that the starting price in the questionnaire is observable as well, therefore Hanemann's treating it as a non-ordered discrete choice variable is obviously not making adequate use of the information provided by the starting price. In this regard, Cameraon uses Censored dichotomous choice model to directly estimate the parameter of the Expenditure Function, more directly and easily obtaining the WTP of the public over environmental goods. The microeconomic theory also demonstrates that the indirect utility function has a dyadic relationship with the Expenditure Function; therefore it can also represent the utility preference of the consumer. In order to prevent excessive biases and to make adequate use of all the data acquired from the questionnaire survey, the study employs a close-ended dichotomous choice method design for the questionnaire, and uses the Expenditure Function model [proposed by Cameron (1988) and Cameron & James (1987)] for calculating the WTP function of the reclaimed water.

In the aspect of factory benefits, in order to make use of the questionnaire survey in determining the price level that the factories are willing to pay for the reclaimed water, and to provide incentives for the factories becoming willing to use the reclaimed water, a hypothetic market must be conceptually established for the factories, to create a bidding function based on individual social and economical characters and the level of bidding prices. The main method is to estimate the acceptable price by way of Cameron's Expenditure Function model based on the WPT of the questionnaire and the percentage of factories that are willing to pay or willing to accept. The empirical model is depicted as follows:

$$Y(Q0,Q1,U0,S) = E(Q0,U0,S) - E(Q1,U0,S) \qquad (1)$$

Y(Q0,Q1,U0, S) is the bidding function of the factories for the reclaimed water; E(Q0,U0,S) and E(Q1,U0,S) are the Expenditure Function. In the formula, S is the price vector of market goods and individual social and economic characteristics vectors, i.e,

$$S = S(PW,PX,SO) \qquad (2)$$

Where SO is the individual social and economic characteristics vector. If the price suggested by the CVM questionnaire is T,

$$Y(Q0,Q1,U0, S) \geq T \qquad (3)$$

the probability for the interviewee to check this bid can be expressed by formula (4):

$$Pr=Pr[Y^*(Q0,Q1,U0,S)-T>u] \qquad (4)$$

Where Y* is observable component, u is observable random component, as shown in Formula (5):

$$Y(Q0,Q1,U0,S)=Y^*(Q0,Q1,U0,S)+u \quad (5)$$

The Bidding Function can be estimated based on the probit model (Cameron & James, 1987) as shown below:

$$Ii=1 \text{ if } Yi > Ti$$

$$=0 \quad \text{otherwise}$$

$$Pr(Ii=1) = Pr(Yi>Ti) = Pr(ui>TI-Xi'B)$$

$$= Pr(ui/\sigma > (Ti-Xi'B)/\sigma)$$

$$= 1-\phi((Ti-Xi'B)/\sigma) \quad (6)$$

where Xi′B is exclaiming variable, ϕ is accumulated probability of intensity function, then the interviewee's bidding valuation can be shown as formula (7):

$$Yi = Xi'B+ui \quad (7)$$

Yet standard binary probit model shall be

$$Ii=1 \quad \text{if } Yi>0$$

$$=0 \quad \text{otherwise}$$

$$Pr(Ii=1) = Pr(Yi>0i) = Pr(ui>-wi'\delta)$$

$$= Pr(zi>-wi'\delta \; / \; v)$$

$= 1-\phi(-wi'\delta / v)$

at this time,

$Yi = wi'\delta + ui$

using the following transformation

$$-(Ti,\ Xi')\begin{bmatrix} -1/s \\ B/s \end{bmatrix} = -wi'\delta$$

$\delta^* = (\alpha,\gamma) = (-1/\sigma, B/\sigma)$

we obtain

$B = -\gamma/\alpha$

$\sigma = -1/\alpha$

$$Yi^* = Xi'B \qquad (8)$$

Where Yi* is the price of reclaimed water estimated by the supplier under the standard binary probit model; this can be used for the calculation of a reasonable price for the reclaimed water.

3. Assuming *u* to be the logistic distribution, the empirical result can be calculated based on the logistic model [Cameron, 1988].

$P(Y)=[1+e-[Yi-Ti]]-1$

Similar to the probit model appraoch, we can obtain

$$Yi^* = Xi'B \qquad (9)$$

Where Yi* is the price of reclaimed water estimated by the supplier under the logistic model; this can be used for the calculation of a reasonable price for the reclaimed water.

2.2. Questionnaire Design

To the demand end, quality and price of the reclaimed water are the major concern. However, different source of raw water can result in different quality levels of reclaimed water when treated by a high-tech reverse osmosis (RO) process, especially in term of electric conductivity (EC). We detail as follows:

(1) Water reclaimed from effluent of large scale wastewater treatment plant by reverse osmosis: capable of reaching quality standard of Taiwan Water Works.

(2) Water reclaimed from effluent of large scale sewage treatment plant by reverse osmosis: capable of reaching quality standard of Taiwan Water Works as well as that of high-class industrial water (EC <10μS/cm).

(3) Water reclaimed from effluent of single plant by reverse osmosis: capable of reaching quality standard of Taiwan Water Works as well as that of industrial soft water (EC <1μS/cm).

First part of the questionnaire is designed for a survey on the basic water consumption in 2008, including company particulars, volume of city water consumption, volume of recycled water, how does the company tackle with city water shortage, whether space is available for installing reclaimed water pipeline system within the company, and other relevant issues.

Second part of the questionnaire assumes future scenarios for using the reclaimed water; three scenarios are designed for the interview, in the purpose of empirical valuation and analysis of beneficial aspects by the factories. Scenarios are as follows:

1. Scenario I

The government guarantees that quality of reclaimed water conforms with city water specifications (this denotes to quality of water reclaimed from effluent of large scale wastewater treatment plant by reverse osmosis), and that “no interruption of supply 365 days a year; quality assurance; loss indemnification on supply interruption,” and that “dedicated pipeline to be installed for reclaimed water delivery, plus with free-of-charge pipe connection”, and that “50% deduction on wastewater treatment charge if total consumption of reclaimed water exceeds 40% of total industrial water consumption of the company”.

2. Scenario II

The government guarantees that quality of reclaimed water surpasses quality of city water (this denotes to quality of water reclaimed from effluent of large scale sewage treatment plant by reverse osmosis, EC<10μS/cm), and that “no interruption of supply 365 days a year; quality assurance; loss indemnification on supply interruption”, and that “dedicated pipeline to be installed for reclaimed water delivery, plus with free-of-charge pipe connection”, and that “50% deduction on wastewater treatment charge if total consumption of reclaimed water exceeds 40% of total industrial water consumption of the company”.

3. Scenario III

The government guarantees that quality of reclaimed water surpasses quality of city water (this denotes to quality of water reclaimed from effluent of single plant by reverse osmosis, EC<1μS/cm), and that “no interruption of supply 365 days a year; quality assurance; loss indemnification on supply interruption”, and that “dedicated pipeline to be installed for reclaimed water delivery, plus with free-of-charge pipe connection,” and that “50% deduction on wastewater treatment charge if total consumption of reclaimed water exceeds 40% of total industrial water consumption of the company”.

For the selection of questionnaire valuation method, the study employs the most easy-to-operate and time saving “Single-bounded dichotomous choice elicitation method” (Boyle & Bishop, 1988) to carry out interviews based on NOAA suggestions.

The selection of WTP in each questionnaire of the three scenarios is determined based on the current city water price in Taiwan and the costs for reclaiming the wastewater. Furthermore, one or several extreme and median values are set to meet theoretical requirements of the Contingent Valuation Method, each scenario having 12 WTPs as shown in Table-1. In another word, the study employs 12 different questionnaires, Q_A through Q_L, with different assignment of the WTP for each scenario.

Table 1 Willingness to Pay of Scenarios (in NT$/ton)

Scenario / No. of Questionnaire	Scenario I	Scenario II	Scenario III
A	3	9	13
B	5	11	15
C	7	13	17
D	9	15	19
E	11	17	21
F	12	18	22
G	13	19	23
H	15	21	25
I	16	22	26
J	18	24	28
K	20	26	30
L	24	30	34

2.3. Sampling Design

The study takes industrial and science parks having a higher water consumption as survey objects, including factories in Hsinchu Industrial Park, Chungli Industrial Park, Taichung Industrial Park, Linyuan Industrial Park, Hsinchu Science Park, Central Taiwan Science Park and Tainan Technology Industrial Park. The above industrial and science parks comprise the sampling zone of the study. For industrial parks, factories having a water consumption exceeding 200CMD are selected as survey objects. For science parks, we call factories one by one to verify their water consumption and exclude those having a low water demand or those lacking willingness to participate our survey. After verification, a total of 347 factories are included in the survey. The survey schedule covers September and October of 2009.

Questionnaire via fax or mail is adopted for the survey. Every returned questionnaire is checked for completion; in case of miss or obvious mistake of key items, a telephone re-check will be made against the particular factory. For factories that fail to return the questionnaire, urging telephone calls will be made. The study sends out a total of 347 questionnaires and receives 47 returns of which 2 are null; the return ratio is 13.54%. Table 3.5 shows questionnaire distribution of the sampling zone. For further understanding of the three scenarios, Table-2 is compiled to statistically manifest the WTP selected for each scenario, and the percentage of factories that are willing to use the reclaimed water at different WTPs corresponding to respective questionnaires of the study.

Table-2 Statistics on questionnaire count of sampling zone factories

Areas \ Count	Send	Return
Hsinchu Industrial Park	20	5
Chungli Industrial Park	13	2
Taichung Industrial Park	1	0
Tainan Technology Industrial Park	6	2
Linyuan Industrial Park	8	4
Hsinchu Science Park	245	26
Central Taiwan Science Park	54	8
Total	347	47
Return Ratio	13.54%	

Table-3 Ratio of WTP of respective questionnaires

Scenario \ Questionnaire No		A	B	C	D	E	F	G	H	I	J	K	L
Scenario I	WTP	3	5	7	9	11	12	13	15	16	18	20	24
	Return Count	3	7	3	3	4	4	1	6	4	6	2	2
	Ratio of Willingness	67	71	33	67	75	50	0	33	50	33	0	0
Scenario II	WTP	9	11	13	15	17	18	19	21	22	24	26	30
	Return Count	3	7	3	3	4	4	1	6	4	6	2	2
	Ratio of Willingness	67	57	0	67	25	25	0	17	25	33	0	0
Scenario III	WTP	13	15	17	19	21	22	23	25	26	28	30	34
	Return Count	3	7	3	3	4	4	1	6	4	6	2	2
	Ratio of Willingness	33	43	0	67	25	25	0	17	0	17	0	0
Total number of questionnaire		29	29	29	29	29	29	29	29	29	29	29	28

Note: Data of null questionnaires are not included in this table. Unit of WTP: NT$/ton. Ratio of Willingness is in %.

4. Results

3.1 Statistics of questionnaire survey data

For comprehending status of water consumption in the sampling zone, and the percentage of willing to pay and willing to use under each WTP, statistics of the questionnaire are arranged as follows:

(1) 2008 Statistics of Water Receipt and Water Utilization

Based on effective questionnaires, the 2008 statistics of water receipt and water utilization of factories is as per Table-4, total consumption of industrial water is 75,276CMD, total of median industrial water consumption is 1,668.37CMD

Table-4 2008 statistics of water receipt and water utilization of factories

Category	Water Rate (CMD)	Median (CMD)	Standard Deviation (CMD)
City water receipt	34,285	757.5978	1739.5329
Ground water receipt	1,327	29.4841	138.9183
Sewage reclamation receipt	9,364	208.0920	853.2404
Rainwater storage receipt	58	1.2030	6.5784
Other water receipt	518	11.5111	67.1053
Recycled water	737,412	16386.9338	76689.7081
Reused water	25,826	573.8516	2105.1290
Vaporized water	3,898	86.6331	319.1864
Total Industrial Water (Excluding recycled water)	75,276	1668.3727	4371.7639

Note: Total industrial water = City Water + Groundwater + Sewage Reclamation + Rainwater Storage + Other water + Reused water + Vaporized water

(2). How did the factory tackle the issue of city water shortage in past droughts

Factories normally have standard procedures and alternative measures to tackle with city water shortage issues, therefore the questionnaire includes a question designed with multiple answers for this item. Ratios on different solutions are (1) Stop production: 4%; (2) Purchase water using water-tankers: 42%; (3) By existing water storage facilities: 64%, with a storage capacity for approximately 2.7 days; (4) Considered about using reclaimed water: 11%; (5) Use in-plant recycled water: 7%; (6) Other Means, such as use of groundwater in accordance with "Regulations on Standard Plant Buildings of Central Taiwan Science Park." This indicates that factories in the sampling zone mostly tackle with city water shortage on their own by existing storage facilities owned by the factory or by purchasing water using water-tankers.

(3). Whether space is available for the installation of pipelines for the water reclamation system.

67% of the factories do no have space for installing pipelines for the water reclamation system and 33% do.

(4). If pipeline service were to be provided for the water reclamation system, where would be the location preferable to the factory as the delivery spot of reclaimed water.

For the future pipeline for delivering reclaimed water, the factory hopes the delivery spot to be (1) near the entrance: 2%: (2) at the utility distribution reservoir: 30%; (3) at a discrete tank in the factory: 42%; (4) at specific utilization spots in the plant: 22%; (5) other locations, such as roof water-tank, or not considered: 3%.

(5). Reasons to the low preference of the factory for using reclaimed water.

Many factors have caused the low preference of the factories to use reclaimed water, therefore the study designs this entry as a multi-choice one. The survey shows that (1) 53% still doubt about quality of reclaimed water; (2) 42% still lack of understanding of characteristics of reclaimed water; (3) 20% fear for affecting the process; (4) 31% worry about unstable quality of reclaimed water; (5) 53% deem difficult and costly to install pipeline; (6) 27% deem potential impact to employee health; (7) 18% expect unstable water supply; (8) 16% possess existing water recycling in the plant; (9) 62% deem price of reclaimed water too high; (10) 44% favor for pipeline of reclaimed water to be provided by the government.

3.2 Empirical results on factories' WTP

For empirical analysis of factories' Willingness to Pay (WTP), the study employs the valuation method developed by Cameron & James (1987) and Cameron (1988) using the software called LIMDEP. In order to avoid influences from extreme sample values, Logit Model is used to establish the valuation formula of WTP (Willingness to Pay); Approximation of Newton's method and maximum likelihood estimation (MLE) are used to valuate each WTP; accuracy of the prediction exceeds 75% although the number of sample is small. Table-5 shows results of regression analysis on WTP in three scenarios:

Table-5 Results of WTP of factories

	Scenario I	Scenario II	Scenario III
WTP of factories (NT$/ton)	13.97	17.8	23.4
Accuracy of the prediction model	82.22%	77.78%	95.00%

Note: All the estimation models are under the 0.5% significant level

(1). Empirical results over Scenario I

Under the assumption that "the government guarantees that quality of reclaimed water conforms with city water specifications, no interruption of supply 365 days a year with assured quality and loss indemnification on supply interruption," and that "dedicated pipeline to be installed for reclaimed water delivery, plus with free-of-charge pipe connection," and that "50% deduction on wastewater treatment charge if total consumption of reclaimed water exceeds 40% of total industrial water consumption of the company", factories are willing to purchase the reclaimed water at an average price of 13.97NT$ per ton, 22.8% of factories in the sampling zone are willing to use reclaimed water, and a ratio of 47% of the returned effective samples. Average consumption of reclaimed water per factory is 291.55CMD, 48.86% to the total consumption of industrial water. Table-6 shows statistics of potential usage and consumption of reclaimed water by factories.

Table-7 shows values of model parameters of Scenario I. In which MAA indicates surveyed WTP; MAW indicates the product of [ratio of maximum reclaimed water to total industrial water] acceptable to the factory multiplied by [the total consumption of industrial water in 2008]; MAN indicates the amount of washing water the factory is willing to use. If the MAA coefficient is negative and MAW and MAN coefficients are positive, the theoretical expectation is deemed met.

Table-6 Statistics of potential reclaimed water application and consumption by factories

Application of reclaimed water	Average ratio of factories willing to accept	Average potential maximum consumption of reclaimed water per factory (CMD)
Process Water	24%	160
Boiler Feed Water	20%	50
Cooling Water	76%	65.75
Washing Water	58%	10.6
Firefighting Water	51%	5.2
Total consumption of reclaimed water		291.55

Note: Average potential maximum consumption of reclaimed water per factory ＝ Total potential consumption of reclaimed water / number of factories that are willing to accept

Table-7 Value of model parameters of Scenario I

	Coeff.	Std.Err.	t-ratio	P-value
ONE	0.170238	1.04835	0.162387	0.871001
MAA	-0.20879	0.099374	-2.10108	0.035634
MAN	2.73873	1.01492	2.69846	0.006966
MAW	0.005193	0.002371	2.19045	0.028491

(2). Empirical results over Scenario II

Under the assumption that "the government guarantees that quality of reclaimed water excels city water specifications, no interruption of supply 365 days a year with assured quality at EC<10μS/cm and loss indemnification on supply interruption," and that "dedicated pipeline to be installed for reclaimed water delivery, plus with free-of-charge pipe connection," and that "50% deduction on wastewater treatment charge if total consumption of reclaimed water exceeds 40% of total industrial water consumption of the company," factories are willing to purchase the reclaimed water at an average price of 17.8NT$ per ton, 16.26% of factories in the sampling zone are willing to use reclaimed water, a ratio of 31% of the returned effective samples. Average consumption of reclaimed water per factory is 303.6CMD, 52.27% to the total consumption of industrial water. Table-8 shows statistics of potential usage and consumption of reclaimed water by factories.

Table-9 shows values of model parameters of Scenario II. In which MBA indicates surveyed WTP; MBW indicates the product of ratio of maximum reclaimed water (acceptable to the factory) to total industrial water multiplied by its total consumption of industrial water in 2008. If the MBA coefficient is negative and MBW coefficient is positive, the theoretical expectation is deemed met.

Table-8 Statistics of potential reclaimed water application and consumption by factories

Application of reclaimed water	Average ratio of factories willing to accept	Average potential maximum consumption of reclaimed water per factory (CMD)
Process Water	27%	171.7
Boiler Feed Water	11%	90
Cooling Water	60%	27.5
Washing Water	44%	10.2
Firefighting Water	38%	4.2
Total consumption of reclaimed water		303.6

Note: Average potential maximum consumption of reclaimed water per factory ＝ Total potential consumption of reclaimed water / number of factories that are willing to accept

Table-9 Value of model parameters of Scenario II

	Coeff.	Std.Err.	t-ratio	P-value
ONE	0.619869	1.34952	0.459327	0.645999
MBA	-0.11373	0.076888	-1.4792	0.139088
MBW	0.006812	0.002982	2.28448	0.022343

(3). Empirical results over Scenario III

Under the assumption that "the government guarantees that quality of reclaimed water excels city water specifications, no interruption of supply 365 days a year with assured quality at EC<1μS/cm and loss indemnification on supply interruption," and that "dedicated pipeline to be installed for reclaimed water delivery, plus with free-of-charge pipe connection," and that "50% deduction on wastewater treatment charge if total consumption of reclaimed water exceeds 40% of total industrial water consumption of the company," factories are willing to purchase the reclaimed water at an average price of 23.4NT$ per ton, 11.05% of factories in the sampling zone are willing to use reclaimed water, a ratio of 22% of the returned effective samples. Average consumption of reclaimed water per factory is 311.6CMD, 49.75% to the total consumption of industrial water. Table-10 shows statistics of potential usage and consumption of reclaimed water by factories.

Table-11 shows values of model parameters of Scenario II. In which MCA indicates surveyed WTP; MCC indicates the ratio of maximum reclaimed water (acceptable to the factory) to total industrial water. If the MCA coefficient is negative and MCC coefficient is positive, the theoretical expectation is deemed met.

Table-10 Statistics of potential reclaimed water application and consumption by factories

Application of reclaimed water	Average ratio of factories willing to accept	Average potential maximum consumption of reclaimed water per factory (CMD)
Process Water	24%	177.3
Boiler Feed Water	9%	62.5
Cooling Water	44%	56
Washing Water	38%	11.5
Firefighting Water	31%	4.3
Total consumption of reclaimed water		311.6

Note: Average potential maximum consumption of reclaimed water per factory = Total potential consumption of reclaimed water / number of factories that are willing to accept

Table-11 Value of model parameters of Scenario III

	Coeff.	Std.Err.	t-ratio	P-value
ONE	8.019489	6.274729	1.278	0.2012
MCA	-0.68726	0.436228	-1.575	0.1152
MCC	1.003743	0.656761	1.528	0.1264
MC	-0.03834	0.029841	-1.285	0.1989

5. Discussion and Conclusions

The study results show the WTP under Scenario I exceed the existing price of city water. We presume the reason behind this is that the factories that are willing to assist the survey had suffered from water shortage in the past operation and therefore are willing to procure the reclaimed water at a cost higher than the city water under the assumed scenario. The quality of reclaimed water in Scenario II excels that in Scenario I, the factories' WTP is therefore raised up. The quality of reclaimed water in Scenario III excels that in Scenario II, the factories' WTP is therefore raised as well.

Reference

.State of California (1978). "Wastewater Reclamation Criteria", Title 22, Division 4, California Code of Regulations, State of California, Department of Health Services. Sanitary Engineering Section. Berkeley, California.

.Department of Health Services, DHS (2001). "California Health Laws Related to Recycled Water", State of California, Department of Health Services, Sacramento CA, June 2001 Edition.

.USEPA (2004). "Guidelines for Water Reuse", EPA 625/R-04/108, Washington, D.C.

.State of Forida (2004). "2003 Reuse Inventory", Department of Environmental Protection, Division of Water Resources Management, Tallahassee, Florida.

.Sheikh, B., Cooper, C. and Israel, K. (1999). "Hygienic evaluation of reclaimed water used to irrigate food crops – A case study", Water Science and Technology, Vol.40 (4-5), pp261-7.

.Asano, T., Burton, F., Leverenz, H., Tsuchihashi, R. and Tchobanoglous, G. (2007). "Water Reuse: Issues, Technology and Applications", McGraw Hill, New York, 1570pp.

.Water Pollution Control Federation (1989). "Water Reuse (2nd Edition)", Manual of Practice SM-3, Water Pollution Control Federation, Alexandria, Virginia.

.El Paso Water Utilities (2007). http://www.epwu.org/wastewater/fred_hervey_reclamation.html

.McEwen, B. (1998). "Indirect potable reuse of reclaimed water", in Asano T. (Ed.) Wastewater Reclamation and Reuse. Chapter 27. Water Quality Management Library, Vol.10, Technomic Publishing, Lancaster, PA.

.Choon Nam et al. (2002). "Singapore Water Reclamation Study- Expert Panel Review and Findings", June 2002. http://www.pub.gov.sg/NEWater_files/download/view.pdf

.Law, I. B. (2003). "Advanced Reuse- From Windhoek to Singapore and beyond", Water Vol.30(5), pp31-36

.Department of Water Resources of Georgia (2007). http://www.mde.state.md.us/assets/document/WatRuse07-7%20Gelot.pdf

.Khan and Roser (2007). "Risk assessment and health effect studies of indirect potable reuse schemes", Center for Water and Waste Technology, School of Civil and Environmental Engineering, University of New South Wales, Australia.

.Swayne, M., Boone, G., Bauer, D. and Lee, J. (1980). "Wastewater in receiving waters at water supply abstraction points", EPA-60012-80-044, US Environmental Protection Agency, Washington, D.C.

.Mekorot, Israel National Water Co. (2003). “Dan Region Project – Groundwater Recharge with Municipal Water”, Brochure of Introduction.

.Idelovitch E., Icekson T.N., Avraham O., and Michail M. (2003). “The long-term performance of Soil Aquifer Treatment (SAT) for effluent reuse”, Water Science Technology Water Supply, Vol. 3, No. 4, pp. 239-246.

.Juanico, M. (2008). “Israel as a case study”, Chap. 27, in Jimenez and Asano (Ed.) Water reuse, an international survey of current practice, issues and needs, pp483-502.

.Smith, V. K., 1993. "Nonmarket Valuation of Environmental Resources: An Interpretive Appraisal" Land Economics, 69（1）:1-26.

.Mitchell, R. C. and R. T. Carson, 1989. Using Surveys to Value Public Goods: The Contingent Valuation Method. Washington, D. C. : Resources for the Future.

.Morrison, Gwendolyn C. 1998., ”Understanding the disparity between WTP and WTA: endowment effect, substitutability, or imprecise preferences?” Economics Letters 59:189-194.

.Hanemann, Michael W., 1991.”Willingness To Pay and Willingness To Accept: How Much Can They Differ?” The American Economic Review 81 (3), June :635-647

.Hanemann, W. M., 1984.” Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses.” American Journal of Agricultural Economics. 66:332-341.

.Cameron , T. A. and M. D. James, 1987. "Estimating Willingness to Pay from Survey Data: An Alternative Pre-Test-Market Evaluation Procedure." Journal of Marketing Research. ,24:389-95.

.Cameron , T. A., 1988. "A New Paradigm for Valuing Non-market Goods Using Referendum Data: Maximum Likelihood Estimation by Censored Logistic Regression. " Journal of Environmental Economics and Management, 15:355-79.

Value of Life Estimates for Children in Metro Manila

Rosalina Palanca-Tan

Ateneo de Manila University

Loyola Heights, Quezon City Philippines

Telefax: (632)4265661

Email: rtan@ateneo.edu

Introduction

One major benefit justifying environmental policies is the reduction in people's risk of death. In developing countries like the Philippines, however, this important benefit is commonly excluded or not properly imputed in environmental cost-benefit analyses and other types of environmental project assessments due to the dearth of studies on the value of mortality risk reduction and the concern on the applicability of values derived in developed countries (benefit transfer). This exclusion may result in underestimated benefits that can cause the defeat of many environmental policy initiatives. This paper presents measures of the value of a mortality risk reduction and of the value of a statistical life (VSL) of a child in Metro Manila based on parents' willingness to pay (WTP) for dengue vaccines for children[1]—the population segment most vulnerable to environmental degradation such as air pollution and water pollution.

The study used a specific intervention scenario, i.e. the dengue vaccine, to avoid the highly hypothetical nature of a general type of intervention that reduces mortality risk

[1] This approach is in line with the "parental sovereignty" perspective on children's welfare which argues parental altruism and parental guardianship or stewardship. It is an alternative to the consumer sovereignty normative perspective-based "children's sovereignty" which assumes that each individual has well-defined preferences and is the best judge of his or her own welfare. Freeman (2003, p. 340) writes: "The children's sovereignty perspective is not ethically attractive. Children are immature and lack the cognitive ability to make choices about health and safety. They may not have well-defined preferences over the full range of alternatives necessary to make reasoned choices. Also, they do not control the financial resources that are required to make trade-offs between money and health or safety."

from all causes (see, for instance, Krupnick et al 2002, Alberini et al 2004, Alberini, Hunt and Markandya 2004, Mahmud 2005, Maskery et al 2007). A multi-purpose intervention can be expected to generate a high incidence of scenario rejection in the Philippine setting where the market is already flooded with health products promising remedies for all problems and the consuming public have grown highly skeptical about these products. The dengue vaccine was chosen as it offered a highly familiar risk and intervention contexts for our respondents. Dengue outbreaks in the Philippines in the last two decades have victimized people across all income classes and have increased their awareness of the risk of death from dengue, particularly of children. Vaccination is also widely accepted in the country as an effective means of preventing diseases in children, and news about positive developments in dengue vaccine research have appeared in Philippine newspaper since 2005. The dengue vaccine is also a private good that is not likely to result in substantial warm glow effects as the virus is not transmitted directly from person to person.

Stated WTP for the dengue vaccine would include not only WTP for the elimination of the risk of dying from dengue but also WTP for reduced morbidity (avoidance of sufferings and pain, inconvenience and loss of income of the sick person and his/her caregivers) and savings on other preventive measures (Cropper et al 2004). This is inherent in a specific intervention VSL scenario where respondents are inclined to consider effects other than the reduction in the risk of dying. This also relates to the issue of VSL estimates being context specific. The non-mortality risk component of WTP for a specific intervention is expectedly context-specific. The goal of most VSL studies, however, is to come up with estimates that can be applied in the assessment of a variety of environmental projects and policies. What existing studies have done so far is to look at how WTP is affected by different risk characteristics such as degree of dread, severity, voluntariness, controllability, personal exposure and perceived immediate occurrence, and to compare VSL estimates in different contexts to arrive at some adjustment ratios. This study undertook a strategy that had not been done in the existing VSL literature. We disentangled the stated WTP into the different benefits that could be derived from the dengue vaccine by asking respondents directly. After the WTP question, respondents were asked to allocate the WTP amount into five benefits that could be derived from the vaccine, one of which was the mortality risk reduction. In a game-like manner that also served to break the monotony of the question-answer sequence of the questionnaire, respondents were given ten tokens and five containers, each labeled with one reason for buying the vaccine. The respondents were asked to think of the five tokens as representing their WTP for the vaccine and to divide them into the five reasons. Only the WTP for the mortality risk reduction was used in the calculation of VSL. To our knowledge, no VSL study had isolated the WTP for mortality risk reduction from the WTP stated by the repondent before VSL was calculated[2].

This study also differs from existing VSL literature in that it elicited WTP for a dengue vaccine for each and every member of the household and used the WTP decisions for all household members in the VSL calculation. Previous VSL studies elicited WTP for mortality risk reduction for only one household member. For examples, Cropper et al (2004) elicited the household head’s WTP for a malaria vaccine for himself/herself and

[2] This may mean that existing VSL estimates based on the specific intervention CVM formulation may be biased upward.

Maskery et al (2007) elicited the respondent's WTP for a nutritional supplement for the youngest child in the household only. It is not difficult to see that eliciting WTP for a particular household member, say the youngest child, can result in biased estimates. We also believe that our approach better reflects the reality of household decision-making wherein the head decides to purchase an individually consumed good for one or several members after considering the needs and wants of all members in relation to the household budget. It is not always clear that this is the case when respondent is asked to focus on just one household member.

As the study deviated from the conventional single VSL-WTP question per respondent structure, we also had to employ a different modeling procedure. This is the third unique feature of the study. We used a two-stage regression model where the household vaccine demand in proportion to household size was regressed with household income and a vector of respondent and other household characteristics in the first stage, and the yes-no response to the dichotomous choice WTP question for each household member was specified as a random effects probit function of the predicted household vaccine demand (as a proportion of household size) derived from the first stage model and a vector of the particular household member characteristics.

Results from our two-stage regression model conformed with economic theory. The vaccine demand (as a proportion of household size) specification exhibited a significant positive income effect while the individual vaccine purchase decisions exhibited a significant negative price effect. The signs of the other explanatory variables in the model were generally in accord with intuition. The VSL estimates for children in

Metro Manila ranged from US$0.70-0.80 million, an order of magnitude comparable to existing VSL estimates in the literature.

Methodology

Survey instrument and implementation

The final form of the survey instrument was the result of a series of key informant interviews (KIIs) with doctors and medical professionals specializing in dengue, infectious diseases and pediatrics; focus group discussions (FGDs) with different types of respondents from low- to high-income households; and questionnaire pre-tests (numbering more than 200 respondents). To allow for some scope tests, two vaccine scenarios were constructed: (1) a dengue vaccine that provides protection for one year and (2) a dengue vaccine that provides protection for ten years. Both types of dengue vaccines were presented as a one-dose vaccine that could be purchased at hospitals, doctors' clinics and drug stores and could be administered either as an injection or oral drops. Five bid levels (dengue vaccine price) were used for both vaccine types: US$ 2 (PhP 100), US$ 10 (PhP 500), US$ 20 (PhP 1,000), US$ 60 (PhP 3,000) and US$ 100 (PhP 5,000). The sample size of 500 respondents consisted of split samples of 50 respondents for each bid price and vaccine duration.

The survey instrument consisted of four parts. Part 1 included a brief introduction on the purpose of the survey, easy to answer questions about the respondent and his/her household, and questions to assess the level of awareness of the respondent about dengue. Part 2 was a short training module on understanding mortality risk reduction. The module included information on mortality risks associated with leading causes of deaths in the Philippines. Apart from familiarizing respondents with the concept of mortality risk reduction, the information provided a basis of comparison for the mortality risk reduction from the dengue vaccine. Preferred over the risk scale by the less educated and lower income FGD and pre-test participants, risk grids were used as visual aid in the survey. A question to test for comprehension was asked at the end of the explanation. The enumerator was instructed to note down the number of times explanation was repeated before respondent was able to give the correct answer. Part 3 introduced the CV scenario by presenting information details on dengue (e.g.: the four dengue virus serotypes, modes of infection, incidence, medication and prevention), the difference between mortality risks from dengue of the 14 years and below age group (1/100,000) and the 15 years and above age group (1/1,000,000) likewise using risk grids as visual aids, and developments in dengue vaccine research. The WTP question, following the dichotomous choice formulation, was phrased in the following way: the respondent was first asked how many vaccines he/she would buy for his/her household members at the stated price, after which he/she was asked who in the household would be given the vaccine. A short “cheap talk” script reminding respondents to consider their budget constraint and to answer in accordance to what they would really do if the vaccine were already available in the market was inserted in the WTP question. Part 3 also included two sets of debriefing questions. One set, addressed to respondents who would buy the vaccine, consisted of three items: (1) the degree of certainty of buying the vaccine, (2) the expenditure item that would be most reduced in order to buy the vaccine, and (3) the relative importance of the different reasons for buying the vaccine. Respondents not buying the vaccine, on the other hand, were first asked if they would take the vaccine for any household members if it were offered for free. A ‘no’ response to this question was followed by a question on the reasons why they would not want the vaccine even if it were free. Finally, part 4 solicited additional socio-economic and health information. These questions were asked last to avoid generating respondents’ disinterest early on the survey. At the end of the interview, the enumerator recorded his/her assessment of the quality of the interview.

The survey was conducted through in-person interviews during the months of February to May 2007 in Metropolitan Manila (MM). MM, one of 17 regions in the Philippines, is the political, economic, social and cultural center of the Philippines. It is one of the more modern metropolises in Southeast Asia and is among the world’s 30 most populous. MM consists of 14 cities and three municipalities. Respondents were drawn from the five largest cities in Metro Manila, namely, Quezon City (accounting for 21% of MM population), Manila (15%), Caloocan (11%), Makati (5%), and Pasig (5%). A sample of 100 respondents was taken from each of the five cities. For each city, a residential barangay with residents belonging to all social classes was randomly selected. Respondents from each barangay were chosen using systematic sampling. Each respondent was randomly assigned a vaccine type and price.

Data analysis

Willingness to pay for a dengue vaccine

A two-stage estimation procedure was undertaken to arrive at the mean willingness to pay for a dengue vaccine for young members of the household age 14 years and below. In the first stage, household demand for dengue vaccines d (expressed in terms of the number of vaccines to be purchased in proportion to the number of household members) was specified as a linear function of the vectors of respondent's characteristics $\boldsymbol{r}$ and household characteristics $\boldsymbol{z}$ (excluding income), and household income y:

$$d = d(\boldsymbol{r}, \boldsymbol{z}, y) \qquad (1)$$

The predicted household vaccine demand derived in the first stage was then included as an explanatory variable in the vaccine purchase decisions for individual household members in the second stage. This would capture the interdependence of the budget constraint in the individual vaccine purchase decisions for each household.

In stage 2, we analyzed the yes-no response to the dichotomous choice CV question using the framework developed by Hanemann based on the random utility model which is briefly discussed below.

Indirect utility, u, depends on h (which takes on the value 1 if the respondent is buying the vaccine for a household member, 0 if otherwise), household income y, a vector of household member characteristics $\boldsymbol{m}$, a vector of respondent and his/her household's characteristics $\boldsymbol{z}$, and a component of preferences that are known only to the respondent and not to the researcher $\varepsilon_{h.}$. This utility function is specified as additively separable in deterministic (v) and stochastic preferences (ε):

$$u(h, y, \boldsymbol{m}, \boldsymbol{z}, \varepsilon_h) = v(h, y, \boldsymbol{m}, \boldsymbol{z}) + \varepsilon_h \qquad (2)$$

As the random part of preference is unknown, only probability statements about yes and no responses can be made. The probability that a bid price *B* for the vaccine is accepted can be expressed as:

$$\begin{aligned} Pr\ (yes) &= Pr\ [v(1, y\text{-}B, m, z) + \varepsilon_1 \geq v(0, y, m, z) + \varepsilon_0] \\ &= Pr\ [v(1, y\text{-}B, m, z) - v(0, y, m, z) \geq \varepsilon_0 - \varepsilon_1] \qquad (3) \\ &= F_\varepsilon\ (\Delta v) \end{aligned}$$

$F_\varepsilon\ (\Delta v)$, the probability that the random variable ε will be less than Δv, represents the cumulative density function of the respondent's true maximum willingness to pay.

We assumed that the stochastic terms ε are independently and identically distributed following a normal distribution with mean of 0 and standard deviation of σ, and used the probit regression procedure to evaluate (3). For the indirect utility specification, we assumed a linear function such that income would disappear in the change in utility term in (3). The parameter estimates from the binary probit model were used to calculate mean willingness to pay *E(B)* according to

$$E(B) = -\ (\beta/\sigma)\boldsymbol{X}/(\beta_B/\sigma) = -\ \beta\boldsymbol{X}/\beta_B \qquad (4)$$

β is a vector of estimated coefficients of all explanatory variables except price (vector ***X)*** and β_B is the estimate for the price coefficient.

Each child member of the household age 14 years old and below for whom the respondent decided to buy or not to buy a vaccine constituted one observation (one data point) in the binary choice data set. Hence, each household (that is, one filled-up questionnaire) contributed a number of data points/observations equivalent to the number of household members 14 years old or younger. Household member characteristics used as explanatory variables were age, gender and a dummy variable for members who were the respondent's own children. As respondent and household characteristics were already incorporated in the household vaccine demand model, only the predicted vaccine demand variable in proportion to the household size was used in the individual choice decision model. Finally, the probit regression procedure was run as an unbalanced panel random effects model to capture the interdependence of the decisions to buy the vaccine for members in each household.

Non-paramteric mean willingness to pay for a dengue vaccine and its variance were calculated using the lower bound Turnbull formula (Haab and McConnel 2003):

$$E_{LB}(B) = \sum_{j=0}^{M} B_j \,(F_{j+1} - F_j) \qquad (5)$$

$$V(E_{LB}(B)) = \sum_{j=1}^{M} (F_j\,(1 - F_j)\,(B_j - B_{j-1})^2 / T_j) \qquad (6)$$

M is the number of bids, B is the bid level, T_j is the number of respondents offered bid price B_j, F_j is the proportion of no responses to bid price B_j, $F_0=0$ and $F_{M+1}=1$.

Isolating the willingness to pay for a mortality risk reduction

Stated willingness to pay for a dengue vaccine includes not only the value attached to the mortality risk reduction effect of the vaccine but also the other benefits that can be derived from the vaccine such as avoidance of pain and suffering, savings on medical and related expenses and avoidance of lost household income. The relative importance of the mortality risk effect vis a vis the other effects depends on the nature of the disease or the cause of death. The willingness to pay for a reduction in the risk of death from dengue, for instance, would differ from that of traffic accidents, cancer and other diseases where the duration and intensity of pain and suffering may be different. A number of studies had shown that willingness to pay for a mortality risk reduction and hence the resulting VSL estimate was context-specific. Hammit and Liu (2004) found that willingness to pay for mortality risk varied according to disease type and latency, and according to the affected body organ, environmental pathway and payment mechanism. In Vassanadumrongdee and Matsuoka (2005), willingness to pay to reduce cancer deaths was found to be influenced by degrees of dread, severity, controllability and personal exposure while willingness to pay to reduce traffic accident was influenced by perceived immediate occurrence. Jones-Lee, Hammerton and Philips (1985) had arrived at a VSL estimate based on motor vehicle crashes (£23 million) that was higher than that based on heart disease (£13 million) and that based on cancer (£7 million).

The goal of many VSL studies is to come up with estimates that can be applied in the assessment of a variety of public projects and policies (e.g.: in transport, health and the environment). VSL estimates based on a particular risk context are applied to other risk contexts commonly through the use of adjustment factors. Revesz (1999), for instance, proposed to adjust the standard VSL used by the U.S. Environmental Protection Agency for use in carcinogenic pollutants emission control by a factor of two for risk chatracterized by involuntariness and uncontrollability, and by a factor of four in case of risks characterized by dread. Some researchers and policy makers, however, are skeptical about the derivation and use of such adjustment factors. For example, due to lack of empirical VSL studies in the air pollution context and reliable information to support adjustment in the road safety-based VSL for air pollution in the United Kingdom, the Department of Health Ministry refrained from quantifying health benefits of air pollution reduction in monetary terms (Dunn 2001).

This paper presents an alternative method to arrive at a VSL estimate that removes the influence of the risk context. The study opted to isolate the willingness to pay for the reduction in mortality risk by asking respondents directly. Respondents were asked to disentangle the amount they are willing to pay for a dengue vaccine into the different benefits that could be derived from the vaccine. Specifically, they were tasked to state the level of importance they accord to the following five reasons for buying the dengue vaccine: (1) to prevent death, (2) to avoid the pain and suffering from being ill with dengue, (3) to avoid incurring medical expenses, (4) to avoid inconvenience and absenteeism from work or school and (5) to avoid having to undertake and spend for other precautionary measures. Our FGDs revealed that respondents would have difficulty allocating a total weight of 100 (in percent) or even 10 (point system) among the five reasons without any computation aid. So we came up with a game-like activity in which respondents were given ten token and five containers. The respondents were told to think of the ten tokens as representing the amount they would pay for the vaccine and to divide them into the five containers according to the weight they give to each reason.

The average weight given to the mortality risk reduction by respondents buying the dengue vaccine, *w*, was used to isolate the willingness to pay for the mortality reduction, *WTP*, from the mean willingness to pay for the dengue vaccine *E(B)*:

$$WTP = w\,E(B) \qquad (7)$$

Value of a statistical life

VSL is the value the individual attaches to a reduction in mortality risk. Technically it is the rate at which the individual would trade money for a small change in the probability of dying, Δr, during a specified time period (Hammit and Graham 1999):

$$VSL = WTP/\Delta r \qquad (8)$$

In the case of the 10-year efficacy vaccine for which payment was to be made only once in the first year, discounting of the mortality risk reduction which would be realized over a period of ten years was undertaken. Viscusi et al (1997) pointed out that insufficient accounting for discounting and time lags before the risk of death appears could overstate people's perception of risks. For this study, we used a 5% discount rate (Hammar and Johhanson-Stenman 2004). This positive discount factor would effect an upward adjustment in the value of the mortality risk reduction from the 10-year efficacy vaccine.

Results and discussion

Respondent and household characteristics

The first three panels of Table 1 give household level descriptive statistics. About a fifth of respondents were male and about a third were smoking. The respondents, on the average, were 34 years old. The respondents' households had a mean monthly income of PhP24,000-25,000 and had five members, on the average.

Table 1

Descriptive statistics

Variable name	Variable definition	1-year vaccine		10-year vaccine	
		Mean	StdDev	Mean	StdDev
Respondent's characteristics					
RespondentGender	=1 if male, 0 if female	0.24	0.43	0.18	0.38
RespondentAge	Years	34.07	6.99	33.49	7.12
Respondent Smoking	=1 if smoking, 0 otherwise	.34	0.47	0.28	0.45
Household characteristics					
HHSize	Number of all hosehold members	5.10	1.52	5.14	1.46
Income	Monthly household income (PhP)	25060	20654	24590	20415
Pasig	Survey site dummy	0.20	0.40	0.20	0.40
Manila	Survey site dummy	0.20	0.40	0.20	0.40
Caloocan	Survey site dummy	0.20	0.40	0.20	0.40
Makati	Survey site dummy	0.20	0.40	0.20	0.40
Dengue-related variables					
DengueFamily	=1 if hh with dengue case/s, 0 otherwise	0.07	0.25	0.07	0.25
DengueOthers	=1 if respondent knew someone who had dengue, 0 otherwise	0.63	0.48	0.59	0.49
Correct	No of correct answers on dengue information questions	6.17	1.14	6.01	1.24
Prevent	No of dengue preventive methods practiced by hh	4.41	1.29	4.33	1.26

FeverFrequency	Frequency of fever in the hh =1 if frequent, 2 if not so frequent, 3 if sometimes, 4 if rarely	3.30	0.67	3.27	0.72
Individual household member characteristics (14 years & below)					
MemberGender	=1 if male, 0 if female	0.50	0.50	0.46	0.50
MemberAge	Years	7.49	4.37	7.50	4.26
RespondentChild	=1 if member is respondent's own child, 0 otherwise	0.98	0.15	0.97	0.15

About 7% of respondents reported cases of dengue in the household while majority personally knew someone who had been ill will with dengue. Survey results reflect a relatively high though not perfect knowledge about dengue. Of the eight dengue information questions, each respondent, on the average, answered six correctly, Almost all were aware about the particular insect (mosquito) that causes dengue but there was less familiarity with the particular characteristics of the mosquito that carries the virus (that it bites during the daytime and lays its eggs in clean waters). Alarmingly, almost half of respondents wrongly thought that the dengue mosquito lays and breeds its eggs only in dirty water. There was also some degree of misconception about the conditions (transmission and immunity) and treatment (blood transfusion) of dengue victims. It appears that the majority of respondents were yet not adequately informed of all ways of preventing dengue as only a fourth of respondents were aware that putting salt in contatiners that accumulate water could prevent mosquito breeding.

As regard dengue preventive methods, households on the average practiced four of the seven methods cited. Almost all households (96%) were doing the relatively easier tasks of regularly cleaning and covering water containers. Three-fourths of the respondents limited outside play of children during the rainy season while only about half practiced the more difficult task of cleaning roof gutters and the more costly method of using insect repellant lotion. While 56% of households were using mosquito-killing chemicals, only 13% were using bednets.

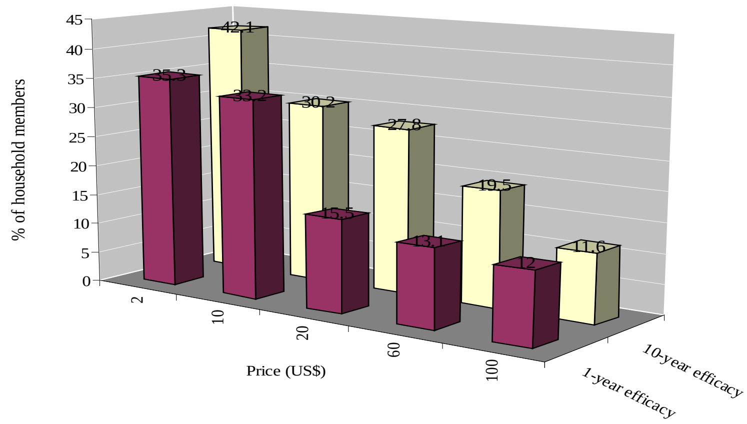
The survey results also confirmed the widespread acceptance of vaccination and the availability of public vaccination programs in the Philippines. Almost all respondents (95-99%) from the low to the high income classes had children in their households given the basic vaccines as provided in the government's Expanded Program on Immunization. Majority of households availed of free vaccination programs of government and charitable institutions.

WTP and VSL

Household vaccine demand model

Figure 1 shows the proportion of household members for whom vaccines would be purchased. The bid function is well-behaved for both vaccine durations. The proportion of household members for whom vaccine would be purchased monotonically declined as vaccine price increased.

Figure 1 Vaccine demand



Results of the ordinary least squares regression run of vaccine demand, expressed as a proportion of household size, are summarized in Table 2. Our household vaccine demand model revealed significant positive income effect. Two dengue-related household profile variables, namely *DengueFamily* and *Prevent*, yielded some siginificant effects on vaccine demand which were in accord with intuition, i.e., households with past case/s of dengue and which undertook more of the dengue preventive measures cited were likely to buy more vaccines. Respondent’s characteristics (i.e., gender, age and smoking) and knowledge about dengue did not yield any consistent as well as significant influence on vaccine demand. Though with varying degrees of significance, dummy variables for survey sites generally had a negative sign, indicating that demand for dengue vaccines was higher for households in Quezon City (the omitted survey site) than in Pasig, Manila, Caloocan and Makati. This could be due to the relatively higher incidence of dengue in Quezon City.

Table 2

Household vaccine demand (as a proportion of household size), Ordinary Least Squares

Explanatory variable	1-year vaccine	10-year vaccine
Constant	0.332**	0.150
Income	0.004***	0.004***
RespondentGender	-0.046	0.049
RespondentAge	-0.004	-0.001
RespondentSmoking	0.070*	0.000
DengueFamily	0.154**	0.114
DengueOthers	0.000	-0.000
Correct	-0.006	-0.008
Prevent	0.014	0.027*
FeverFrequency	-0.020	0.000
Pasig	-0.127**	0.000
Manila	0.010	-0.047
Caloocan	-0.014	-0.104*
Makati	-0.079	-0.097
R-squared	0.170	0.140
Number of observations	250	250

*** significant at α=0.01, **significant at α=0.05, *significant at α=0.10

Vaccine purchase decision for individual child household members

Table 3 presents the results of the binary probit random effects model of the respondents' stated decisions to purchase a dengue vaccine for each household member age 14 years and below. Results for both the 1-year and 10-year efficacy vaccines conformed with economic theory and intuition. Vaccine price had a siginifcant negative effect on the respondent's decision to purchase a vaccine for a household member while predicted vaccine demand had a significant positive effect. The probability of the respondent buying a vaccine for a member was also significantly higher for younger members and for members who were the respondent's own children. Gender of the household member revealed no systematic and significant effect on the decision to buy the vaccine.

Table 3

Willingness to pay for a dengue vaccine for household members 14 years old and below, Binary probit model with unbalanced panel random effects

Explanatory variable	1-year vaccine	10-year vaccine
Constant	-8.434*	-13.676**
Vaccine Price	-0.0021***	-0.0027**
Predicted vaccine demand (in proportion to household size)	36.076***	53.363**
Member age	-0.319***	-0.579**
Member gender	0.068	-0.646
Member is respondent's child	6.648	9.862**
Random effects	0.973***	0.983***
Log-likelihood	-181.688	-159.864
Number of observations	521	479

*** significant at α=0.01, **significant at α=0.05, *significant at α=0.10

Using the results of the random effects probit model, mean willingness to pay for a dengue vaccine for children 14 years and below was calculated to be about US$35

(PhP1,729) for the 1-year duration vaccine and US$41 (PhP2,047) for the 10-year duration vaccine (first panel of Table 4).

Non-parametric mean willingness to pay for the dengue vaccine calculated using the Turnbull method are shown in the second panel of Table 4. Non-parametric WTP were slightly lower than the parametric estimates for both vaccine durations.

Table 4 Mean willingness to pay for a dengue vaccine for children 14 years and below

	1-year duration	10-year duration
Parametric		
US$ (PhP)	34.57 (1,729)	40.95 (2,047)
Non-parametric (lower-bound estimates)		
US$ (PhP)	30.4 (1,520)	37.0 (1,852)

Mean WTP for the 10-year duration vaccine was only slightly higher than mean WTP for the 1-year duration vaccine, and the difference was much smaller than the proportionality requirement of the external scope test. Nearly all previous studies of mortality risk reduction failed the extrenal scope test. From among 25 CVM-VSL literature reviewed by Hammit and Graham (1999), only nine allowed for an external magnitude test and all nine studies violated the proportionality assumption[3]. More recent CVM-VSL studies employing visual aids and risk comprehension training modules were no exception (see, for instance, Hammit and Liu 2004, Alberini et al 2004, Liu et al 2005, Maskery et al 2007).

[3] Three of the nine did not even satisfy the expected positive relationship between WTP and the risk reduction magnitude.

Value of a statistical life

Reflecting the high literacy rate in the Philippines, particularly in highly urbanized MM, respondents generally understood the concept of mortality risk. More than four-fifths of respondents correctly answered the comprehension test question for the short module on understanding mortality risks after only one explanation. About 16% required one repetition of the explanation while the remaining 3% required two repetitions. Thus, we feel reasonably confident that respondents understood and took into consideration the mortality risk reduction that the dengue vaccine would bring about.

Results of the debriefing questions on the relative importance of the different reasons for buying the dengue vaccine for young members of the household 14 years old and below are summarized in Table 5. On the average, yes respondents gave the mortality risk reduction effect of dengue a weight of 38.7% (or a 95% CI of 35.7-41.7%). This result indicates that although the mortality risk reduction was considered most important among five reasons for buying the dengue vaccine, the weight attached to it was much lower (less than half) than the 100% weight implicitly assumed in VSL studies that based estimates on the entire willingness to pay for an intervention.

Table 5 Relative importance of reasons for buying the vaccine

	Mean	Std Dev
1. to prevent death from dengue	3.87	1.65
2. to avoid the pain and suffering from being ill with dengue	1.91	1.12
3. to avoid incurring medical expenses	1.34	1.11

4. to avoid the inconvenience and prevent being absent from work or school	1.58	1.26
5. so that it will not be necessary for us to take and spend for other precautions (such as using anti-mosquito lotion, mosquito nets, mosquito killers, etc.)	1.31	1.24

We used the stated weight in Table 5 to decompose the willingness to pay for a dengue vaccine and isolate the mean value attached by the respondents for a reduction in the risk of dying of a child in their households. Following Hammit and Liu (2004) and Vassanadumrongdee and Matsuoka (2005), VSL was calculated as the average of the values for the two risk reduction magnitudes. The WTP and resulting VSL estimates are shown in Table 7. The value of life estimates for a child 14 years old or younger in Metro Manila ranged from US$0.70 million to US$0.80 million, about 118-133 times of annual income. Our results are fairly within the range of estimates derived in recent survey-based VSL estimates in the region. Vassanadumrongdee and Matsuoka (2005) came up with VSL estimates of US$0.7-1.5 million, about 100-170 times of annual income, in their study with scenarios on traffic accidents and air pollution in Bangkok in 2003. Hammit and Liu's (2004) liver cancer and non-cancer diseases scenarios resulted in VSL estimates of US$0.5-1.1 million, 36-80 times of annual income in Taiwan in 2001.

Compared to other child VSL estimates, our estimates for Metro Manila are lower than previous estimates for the US using the revealed preference averting behavior methods (e.g.: Mount et al's estimate of US$2.6-7.7 million based on vehicle fatality rates and costs in 1997 and Jenkins et al's estimate of US$1.1-2.7 million based on bicycle helmet demand in 1997) but much higher than the recent child VSL estimate for Bangladesh of US$30-60,000 (Maskery et al 2007).

Table 7 WTP for a mortality risk reduction and VSL estimates for children in Metro Manila

	Parametric	Non-parametric
WTP US$ (PhP)	14.61 (699)	13.04 (652)
VSL US$ millions (PhP millions)	0.80 (39.9)	0.70 (35.2)
VSL/Annual Income	133	118

Concluding remarks

We arrived at a measure of the value of statistical life of a child in Metro Manila, which to our knowledge is the first VSL estimate for the Philippines and one of the very few CVM-based VSL estimates for children. Our estimate was derived from the willingness to pay for a hypothetical dengue vaccine—a familiar risk and intervention context for Filipinos, particularly for children.

Our study differs from existing literature in two ways. First, WTP for a dengue vaccine was elicited for each and every household member instead of only one household member. We believe that our approach better reflects the reality of household decision-making wherein the head decides to purchase an individually consumed good for one or several members after considering the needs and wants of all members in relation to the single household budget constraint. Likewise, a different modeling procedure was undertaken. We used a two-stage model where the household vaccine demand in proportion to household size was regressed with household income and a vector of respondent and other household characteristics in the first stage, and the yes-no response to the dichotomous choice WTP question for each household member was specified as a random effects probit function of the predicted household vaccine demand derived from the first stage model and a vector of the particular household member characteristics.

Second, WTP for the mortality risk reduction was isolated from the stated WTP for the specific health intervention before VSL calculation. We found out that although the mean weight for the mortality risk reduction was larger than the weights for the other reasons for taking the vaccine, it was only a third of the total. This result suggests the extent of likely deviations of past specific intervention-based VSL estimates when applied to other risk contexts—a finding which is not inconsistent with studies recommending risk context adjutment factors for VSL estimates of as large as 2-4 times (Revesz 1999 and Hammit and Liu 2004).

Our models conformed with predictions of economic theory—our household vaccine demand model yielded a significant positive income effect while our random effects probit model for vaccine purchase decisions yielded a significant negative price effect. Our VSL estimates compared well with existing CVM-VSL estimates in the literature—relatively lower than those derived for developing countries and falling in the lower range of estimates for slightly richer countries in the region.

References

Alberini, Anna, Alistair Hunt, and Anil Markandya. 2004. Willingness to Pay to Reduce Mortality Risks: Evidence from a Three-country Contingent Valuation Study. In FEEM working paper. Milan, Italy.

Bateman, Ian J. et al. 2002. Economic Valuation with Stated Preference Techniques: A Manual. Cheltenham, UK: Edward Elgar.

Blomquist, Glenn C, Ted R Miller, and David T Levy. 1996. Values of Risk Reduction Implied by Motoris Use of Protection Equipment: New Evidence from Different Populations. Journal of Transport Economics and Policy 30:55-66.

Carlin, Paul S and Robert Sandy. 1991. Estimating the Implicit Value of a Young Child's Life. Southern Economic Journal 58(1):186-202.

Carlsson, Fredrik and Olof Johansson-Stenman. 2000. "Willingness to pay for improved air quality in Sweden," Applied Economics, 32:661-669.

Corso, Phaedra S., James K. Hammitt, and John D. Graham. 2001. "Valuing Mortality-Risk Reduction: Using Visual Aids to Improve the Validity of Contingent Valuation," Journal of Risk and Uncertainty, 23:2, 165-184.

Cropper, Maureen, Mitiku Haile, Julian Lampietti, Christine Poulos, and Dale Whittington. 2004. "The demand for a malaria vaccine: evidence from Ethiopia," Journal of Development Economics, 75, 303-318.

Dunn, Helen. (2001). "UK Perspective on Valuing Mortality Risk in the Air Pollution Context." In Proceeding Paper in Abt Associates (ed.), Economic Valuation of Mortality Risk Reduction: Assessing the State of the Art for Policy Application, Workshop document.

Freeman, A. Myrick III. (2003). The Measurement of Environmental and Resource Values: Theory and Methods, second edition. Washington, D.C.: Resources for the Future.

Haab, Timothy C. and Kenneth E. Connell. 2003. Valuing Environmental and Natural Resources: The Econometrics of Non-market Valuation. Edward Elgar.

Hammar, Henrik, and Olof Johansson-Stenman. (2004). ”The value of risk-free cigarettes-do smokers underestimate the risk?” Health Economics, 13, 59-71. *

Hammitt, James K., and John D. Graham. (1999). “Willingness to Pay for Health Protection: Inadequate Sensitivity to Probability?” Journal of Risk and Uncertainty, 18(1), 33-62.

Hammitt, James K., and Jin-Tan Liu. 2004. “Effect of Disease Type and Latency on the Value of Mortality Risk,” Journal of Risk and Uncertainty 28:73-95.

Jenkins Robin R, Nicole Owens and Lanelle Bembenek Wiggins. 2001. Valuing Reduced Risks to Children: The Case of Bicycle Safety Helmets. Contemporary Economic Policy 19(4):397-408.

Johanneson, Magnus and Per-Olov Johansson. (1997). “Quality of life and the WTP for an increased life expectancy at an advanced age,” Journal of Public Economics, 65, 219-228.

Jones-Lee, Michael, M. Hammerton and P.R. Philips (1985). “The Value of Safety: Results of a National Sample Survey,” Economic Journal 95, 49-72.

Krupnick, Alan, Anna Alberini, Maureen Cropper, Nathalie Simon, Bernie O’Brien, Ron Goeree, and Martin Heintzelman. (2002). ”Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents,” Journal of Risk and Uncertainty, 24, 161-186.

Liu, Jin-Tan, James K. Hammitt, Jung-Der Wang and Men-Wen Tsou. (2005). "Valuation of the risk of SARS in Taiwan," Health Economics, 14, 83-91.

Mahmud, Minhaj. (2005). "Contingent Valuation of Mortality Risk Reduction in Developing Countries: A Mission Impossible?" Measuring Trust and the Value of Statistical Lives: Evidence from Bangladesh, Ph.D. Dissertation, Göteborg University, 145, 82-117.

Maskery, Brian, Ziaul Islam, Jacqueline Deen and Dale Whittington. 2007. "An Estimate of the Economic Value that Parents in Rural Bangladesh Place on Ex-ante Mortality Risk Reductions for their Children."

Mount, Timothy, Weifeng WengWilliam Schulze and Laurie Chestnut. 2001. "Automobile Safety and the Value of Statistical Life in the Family: Valuing Reduced Risk for Children, Adults and the Elderly", Paper presented at the Association of Environmental and Resource Economists Workshop (Assessing and Managing Environmental and Public Health Risks), June 13-15, Bay Harbor, ME.

Persson, Ulf and Magnus Cerdevall. (1991). "The Value of Risk Reduction: Results from a Swedish Sample Survey." IHE Working Paper 1991:6, Lund: Swedish Institute for Health Economics.

Persson, Ulf , Anna Norinder, Krister Hjalte, and Katarina Gralen. (2001). "The Value of Statistical Life in Transport: Findings from a New Contingent Valuation Study in Sweden," Journal of Risk and Uncertainty, 23, 121-134.

Revesz, Richard L. (1999). "Environmental Regulation, Cost-Benefit Analysis, and the Discounting of Human Lives," Coloumbia Law Review 99(4), 941-1017.

Viscusi, W. Kip, and Joseph A. Aldy. (2003). "The Value of a Statistical Life: A Crititcal Review of Market Estimates Throughout the World," Journal of Risk and Uncertainty 27(1), 5-76.

Viscusi W.Kip, Hakes JK, Carlin A. 1997. Measures of mortality risk. Journal of Risk and Uncertainty. 1997;14(3): 213-233.

Vassandumrongdee, Sujitra, and Shunji Matsuoka. 2005. Risk Perceptions and Value of a Statistical Life for Air Pollution and Traffic Accidents: Evidence from Bangkok, Thailand. Journal of Risk and Uncertainty 30(3):261-287.

Whittington, Dale. (2002). "Improving the Performance of Contingent Valuation Studies in Developing Countries," Environmental and Resource Economics, 22:323-367.

Whittington, Dale. (1996). "Administering Contingent Valuation Surveys in Developing Countries," Economy and Environment Program for Southeast Asia (EEPSEA) Special Paper.

Whittington, Dale, V. Kerry Smith, Apia Okorafor, Augustine Okore, Jin Long Liu and Alexander McPhail. (1992). "Giving Respondents Time to Think in Contingent Valuation Studies: A Developing Country Application," Journal of Environmental Economics and Management, 22, 205-25.

Investigating the WTP/WTA for an Urban Municipal Waste Incinerator in Northern Taiwan

Wang-Kun Chen[1], Takaaki Kato[2]

1. Department of Environment and Property Management, Jinwen University of Science and Technology, Taiwan.

2. Faculty of Environmental Engineering, University of Kitakyushu, Japan.

Abstract

The contingent valuation (CV) method is convenient in surveying the social economic problem. For the nuisance facility, such as the incinerator or land fill site, it is necessary to know the opinion about the residents in the neighboring area. This study estimated the influence of public facility to the neighboring community by the CV method. We have investigated the willing to pay (WTP) and willing to accept (WTA) value for an incinerator in northern Taiwan area. Ten districts were surveyed to know the attitude about the government policy of compensate rate and what are the things they care about most. The results reveal that the people more than forty years old care about the impact of noise. While the people more than fifty years old are more concerned with the health effect of incinerator and are willing to pay more money for their health insurance. People with lower education background care about the truck noise, however, the people with higher education background care more about the air quality. As to the compensation rate from the government, the results of this study indicate that most of the people satisfied with the present compensation rate.

Keywords:

Contingent valuation, WTP, WTA, incinerator pollution, community communication

I. Introduction

The municipal incinerator is important to the treatment of solid waste. However, it may influence the neighboring environment so the people do not like to have the incinerator in its community. This is the so-called "Not In My Backyard (NIMBY)" phenomenon. The environmental economist tries to solve this problem by the contingent valuation (CV) method. The people living in the neighboring area could be compensated by certain amount of feedback fund to compensate their loss in living standard and environmental quality. The quantitative value can be obtained by this method. If the amount of compensation meets the expectation, then the problem can be solved by a more peaceful way.

The incinerator produces the pollution such as the waste gas, waste water, noise, landscape etc. It is not easy to evaluate the value of the effect. Scientist investigate this value by an indirect way, which is called "willing to pay(WTP) or "willing to accept(WTA)" that is to measure the amount to what extent the people is willing to pay for the improvement of their environment or what amount of compensation they will accept for their reduction of environmental quality.

As Taiwan is a very small island, the installation of municipal incinerator face the strong against problem from the community resident. Since it is necessary to find a place for the location of incinerator, the problem has to be solved by a more efficient way. The compensation fee for the neighboring community is very usual for the government to solve the problem. If it could be accept by the community people, then the externality can by compensated.

The Hsintien municipal incinerator is located in Hsintien City of Taipei County. It is the example of municipal incinerator located in the downtown of Hsintien city. Many people lived in the neighboring area. Although they try to improve the efficiency of pollution control, the people still worry about the influence of its contamination. The Hsintien city hall has provided the budget for the compensation. However, the allocation and amount to the community is always the big problem for the government. A more scientific way to calculate the fee is necessary for the answer.

In order to help the decision maker to solve this problem, this study calculate the external costs by the contingent valuation (CV) method. We have investigated the willing to pay (WTP) and willing to accept (WTA) value for Hsintien incinerator in the neighboring area. Ten districts were surveyed to know the attitude about the government policy of compensate rate and what are the things they care about most.

There are some studies about the WTP in Taiwan, Wu has studied the relationship among attraction, satisfaction and loyalty, and visitor's willingness to pay of the Chiayi International Band Festival. (Wu, 2005) Chen has done a case study in Kaohsiung and Taichung City about valuating and analyzing the people for willingness to pay of food waste recycling and reusing. (Chen, 2004) Some researchers execute the study about the community residents' cognition of the cultural heritage preservation and willingness to pay. (Gao, 2004) (Chen, 2003) Huang apply CVM to analyze of willingness to pay for local environmental tax at green island. (Huang, 2004) Wu have studied the marketing strategy and consumer satisfaction. (Wu, 2004) Chen studied the prices of willingness to pay of wellness tourism based on deep sea water resources in Hualien County. (Chen, 2007)

Some researchers have studied the feedback fund for the public facilities. Lin stuidied the feedback mechanism in Taiwan's urban land use rezoning system in Taichung city.(Lin, 2000) Hsu has a case study of Maioli City about the cash rewards on B.O.T incineration factory. (Hsu, 2007) Lin also completed the case study of compensation institution of a municipal solid waste incineration in Lucao, Chiayi County. (Lin, 2004) Hung use Taipei Songshan Airport as an example for the study of effect of implementing the airport compensation. (Hung, 2007) Chen has the case study based on the contribution usage of the Kung-Liao nuclear power plant for the research of the policy-making mechanism involving environmental pollution. (Chen, 2006)

II.Basic Information

Hsintien incinerator is located in Hsintien City of Taipei County. It processes 900 tons of garbage from Taipei County. An advantage of burning garbage is to produce the steam power generation to increased energy use efficiency. The main steam generated by the boiler for steam turbine generator to generate the electricity. Part of them was used for the equipment in the plant, and most of the remaining power can be re-sold to Taiwan Power Company.

The main service area is not only for Hsintien city, they also process the garbage from the neighboring city such as Yonghe, Pinghsi, Pinglin, Wulai, Shihting, Juifang, Kungliao, Sungai etc. Waste gas of the incineration plant was treated by pollution control equipment and then emit from the chimneys. The Hsintien city hall has annually compile the budget for the compensation of Hsintien municipal incinerator to the neighboring area. The total amount is shown in Table 1. The allocation of this budget was by the total population in each village as shown in Table 2.

Currently Hsintien City Hall has the following specification for the feedback fund usage: 1. Matters relating to environmental or amenity, to process environmental disinfection. Environmental rectification. clean-up activities, beautify the environment green（Such as: planting trees. Pot. paint. painting. street lamps; 2. Matters relating to enhance the living standards of environmental quality, or education and cultural; 3.To build the community road fen. ; 4. Road repair. clearing ditches. monitoring systems. extinguishers maintenance of public facilities such as dressing etc.; 5. Other environmental or landscape related matters. 6.Other related issues to enhance the environmental quality of life or education and culture level; 7. Issues related to environmental monitoring and identification; 8. Subsidies in the water and electricity within the household; 9. Application for water and electricity subsidies, notice printing. record keeping and stationery fees; 10. Collection and purchasing of the various artifacts and equipment in Ankeng museum.

III. Research Method

3.1 Theoretical study of contingent valuation (CV) method

The contingent valuation method (CVM) is used to investigate economic values for all kinds of ecosystem and environmental services. It can be used to investigate both use and non use value, and it is the most widely used method for investigating non-use values. It is also the most controversial of the non-market valuation methods.

There are five steps in performing the contingent valuation method (CVM). The first is to define the valuation problem. Then to make preliminary decisions about the survey itself, including whether it will be conducted by mail, phone or in person, how large the sample size will be, who will be surveyed, and other related questions. And then the actual survey design, the actual survey implementation, and to compile, analyze and report the results.

3.2 Research framework and procedure

The framework and procedure of this research is shown as figure 1.

There are twenty two villages which received the feedback compensation. We selected ten villages for sending out the questionnaires. These villages are: Anhe village, Yong-an Village, Hsinhe village, Yongping village, Gonglun village, Anchang Village, Dean Village, Daguan Village, Mingcheng Village, and Hsiaocheng Village. These areas are more close to the Hsintien incinerator, and the environmental quality is impacted by the operation of this plant. The population in the area where questionnaires sent out is shown in Table 3.

IV. Results and Discussion

4.1 Descriptive Statistics of survey results

The questionnaires were sending out through the channel of the office of the village head. They were asked to answer all the questions in the questionnaire. Five hundred pieces were sent out and 450 were received. The effective questionnaires amount was 415 pieces. The total recovery rate was 90 percent. The recovery rate of this survey is shown in Table 4.

The descriptive statistic was shown in the following tables. Table 5 is the gender distribution for the person interviewed. Table 6 is the age distribution for the person interviewed. Table 7 is the place of residence distribution of the number issued for feedback compensation. Table 8 is the table of population by education for the person interviewed. Table 9 is the marital status for the person interviewed. Table 10 is the occupational allocation for the person interviewed. And Table 11 is the monthly income distribution for the person interviewed.

4.2 Cognitive Dimension for the feedback fund

A. Do you clearly understand there is an incineration plant feedback compensation for the village from the government? 1.□very clear 2.□clear 3.□no comment 4.□not clear 5.□ absolutely not clear

About the answer of question" Do the residential people clearly understand the feedback compensation for the village from the government?" there are 39% answer is "very clear", 34% answer is "clear", 18% answer is "no comment", 7% is "unclear", and 2% is "very unclear". The result reveals that most of the residents aware the feedback compensation for the village from the government. (Figure 2)

B. Do you clear understand the usage of feedback compensation in your village? 1.□very clear 2.□clear 3.□no comment 4.□not clear 5.□absolutely not clear

About the answer of question" Do you clear understand the usage of feedback compensation in your village?" there are 11% answer is "very clear", 28% answer is "clear", 39% answer is "no comment", 16% is "unclear", and 6% is "very unclear". The result reveals that the people are still not aware of the usage of feedback compensation in their village. (Figure 3)

C. Do you know that the process of the usage, distribution, management, decision, is through the following procedure? 1. Village of Lane office provide information and proposal to the hall; 2. Feedback fund management committee meeting and have the resolution. 3. City hall compiles the budget for processing. 1.□ very clear 2.□ clear 3.□ no comment 4.□ not clear 5.□ absolutely not clear

About the answer of question" Do you know that the process of the usage, distribution, management, decision, is through the following procedure?" there are 7 % answer is "very clear", 18 % answer is "clear", 46 % answer is "no comment", 22 % is "unclear", and 7 % is "very unclear". The result reveals that most residents do not know the process. (Figure 4)

D. Do you agree with the present decision process of the usage of feedback compensation? 1.□ strongly agree 2.□ agree 3.□no comment 4.□ not agree 5.□ strongly disagree

About the answer of question” Do you agree with the present decision process of the usage of feedback compensation?” there are 14 % answer is “strongly agree”, 26 % answer is “agree”, 39 % answer is “no comment”, 12 % is “disagree”, and 9 % is “strongly disagree”. The result reveals that certain amount of residents do not agree with the present method for decision making process. (Figure 5)

E. Which do you think is the best for the usage of feedback compensation in the village 1.□ by all the people in the village 2.□ by the representative in the village committee 3.□ by all the village head committee4.□ by the village head himself 5.□ by the hall 6.□other?

About the answer of question” Which do you think is the best for the usage of feedback compensation in the village” the highest is “by all the people in the village”, the second highest is “by the village head himself”, and the third is “by the representative in the village committee”. There are 39 % person believes the decision “by all the people in the village” in the village is the best solution. The lowest in “by the hall” and only 4 % support this choice.

Referring to the results of the survey results, most of the peoples interviewed hopes to participated in the decision making process by all the residents in the village committee“. (Figure 6)

F. Do you agree to participate in the decision making process of the feedback fund usage of your village? 1.□ strongly agree. 2.□ agree3.□ no comment 4.□ disagree 5. □ strongly disagree

About the answer of question” Do you agree to participate in the decision making process of the feedback fund usage of your village?” the highest is “strongly agree”, the second highest is “agree”, and the third is “no comment”.40 % of the person interviewed showed their opinion in “strongly agree” to participate in the decision making process of the feedback fund. Only 1 % does not agree to participate in this event. The result reveals that most of the residents are willing to participate into the decision making procedure. (Figure 7)

G. Hsintien incinerator has operated for fifteen years, do you agree that it does not contaminate? 1.□ strongly agree 2.□ agree3.□ no comment 4.□ disagree 5.□ strongly disagree
(if you choose”disagree”or”strongly disagree”, please describe what kind of pollution you observed.)

About the answer of question” Hsintien incinerator has operated for fifteen years, do you agree that it does not contaminate?” the highest is “disagree”, the second highest is “agree”, and the third is “strongly agree”. 33 % of the person interviewed showed their opinion in “strongly disagree” that the incinerator do not contaminated. 28 % agree that the incinerator do not contaminate. The result reveals that most resident do not understand the operating of this incinerator. (Figure 8)

H. How do you think about intension of such funds (Incinerator feedback fund)? 1.□ pollution compensation 2. □ public relationship of the neighboring community 3. □ both are true 4. □ both are false 5. □not clear

About the answer of question” How do you think about intension of such funds (Incinerator feedback fund)?” the highest is “pollution compensation”, the second highest is “public relationship of the neighboring community”, and the third is “both are true”. 33 % of the person interviewed showed their opinion that they believe the feedback fund is a kind of pollution compensation. 31 % of them believed that the meaning of feedback compensation is for the public relationship of the neighboring community. The results reveal that most of the people think it is a feedback fund with the characteristic of compensation. (Figure 9)

I. Do you think that it is because of the feedback compensation so that you will not against the install of this incinerator? 1.□ strongly agree 2.□ agree 3.□ no comment 4.□ disagree5.□ strongly disagree

The survey result shows that the people will not change their attitude and stop to against the installation of this incinerator because of the feedback compensation fund. (Figure10)

J. Do you agree that the feedback fund will influence the residents’ intension to move into or out of the “compensation area”? 1.□ yes 2.□ no 3.□ no comment 4.□ others (please describe)

About the answer of question” Do you agree that the feedback fund will influence the residents’ intension to move into or out of the “compensation area?” the highest is “no comment”, the second highest is “no”. 42.1 % of the person interviewed showed their opinion that they had no comment on whether the feedback fund will influence their intension to move into or out of the compensation area. Another 38.2 % showed their opinion that the feedback fund will not influence their intension. The results reveal that they thought the feedback fund is only a form of compensation and will not influence their intension to move in or out. (Figure11)

K. Where do you know the information about the feedback compensation?【multiple choice】 1.□ newspaper 2.□ radio 3.□TV 4.□leaflets from the county government and village office 5.□ internet information 6.□ village committee 7.□ village head 8.□ relative, friend, or neighboring people 9.□ others(please describe)

About the answer of question” “Where do you know the information about the feedback compensation?” the highest is “village head”, the second highest is “village committee”, and the third is “relative, friend, or neighboring people”. 86.0 % of the person interviewed showed that their information comes from village head, village committee, and relative, friend, or neighboring people. 42.1 % of the person interviewed showed that they got the information about the feedback fund from the village head. However, the most popular public media as newspaper. Radio and TV only have 23.9 %. The results reveal that the people did not rely on the public media to obtain this information. (Figure 12)

4.3 Satisfactory Dimension for the feedback fund

A. Do you satisfied with the amount of feedback compensation for your village? 1.□strongly satisfied 2.□satisfied 3.□no comment 4.□not satisfied5.□strongly not satisfied (please describe)

Most of the person interviewed has no comments on the amount of feedback compensation for their village; however, they will not refuse the higher amount of compensation because it is benefit for the improvement of their living quality. The results of this survey reveal that most people satisfied with the present amount of feedback amount. (Figure 13)

B. Do you satisfied with the present usage of the feedback fund in your village? 1.□ strongly satisfied 2.□ satisfied 3.□no comment 4.□ not satisfied5.□strongly not satisfied (please describe)

Most of the person interviewed showed that they are satisfied with the present usage of the feedback fund. (Figure 14)

C. Do you satisfied with the amount of feedback compensation for your basic utilities? 1.□ strongly satisfied 2.□ satisfied 3.□ no comment 4.□ not satisfied 5.□ strongly not satisfied

Generally, the residents thought that the fee for utility is actually helping them in the living quality, and they can reduce the living expense. Therefore the results show that most people are satisfied with this method. (Figure 15)

4.4 Suggestion Dimension for the feedback fund

A. as described in the" Self-government Ordinance of feedback fund of Hsintien incinerator", the area for compensation area is limited to the local area near the incinerator. Do you thick it is reasonable? 1.□ Unreasonable, the feedback scope should be expanded 2.□ Unreasonable, the feedback scope should be narrowed 3.□ Reasonable, no need to changes 4.□ no comment

About the answer of question" As described in the" Self-government Ordinance of feedback fund of Hsintien incinerator", the area for compensation area is limited to the local area near the incinerator. Do you think it is reasonable?" the highest is "no comment", the second highest is "reasonable, no need to changes". 77.5 % of the person interviewed showed their opinion that they have no comment about the "Self-government Ordinance of feedback fund of Hsintien incinerator". 36.9 % of the person interviewed showed their opinion that the "Self-government Ordinance of feedback fund of Hsintien incinerator" is unreasonable. The reason is because the feedback fund is for the people in the village, if more people shared in the fund, than they have less money from the compensation. Therefore they do not intent to change the ordinance to prevent more people engaged in the amount. (Figure 16)

B. Which do you think is the better way for the feedback fund allocation level?（single choice）1.□ Allocate by the population proportion in each village 2.□ Allocate by the area proportion in each village 3.□ Allocate by the distance to the incinerator in each village 4.□ Allocate by the weighting factor consider the population, area, distance to the incinerator in each village 5.□ Allocate by the total amount divided by the number of village 6.□ Now it is reasonable and no need to changes 7.□ no comment

About the answer of question" Which do you think is the better way for the feedback fund allocation level?" the highest is "Allocate by the population proportion in each village", the second highest is "Allocate by the total amount divided by the number of village", and the third is

“Now it is reasonable and no need to changes”. 34.2 ％ of the person interviewed believes that the best is to allocate by the population proportion in each village. 18.2％ of the person interviewed believes that the best is to allocate by the total amount divided by the number of village. And 5.2 ％ of the person interviewed believes that it is reasonable now and no need to changes. The lowest is to allocate by the area proportion in each village. Only 2.5％ support this method. There are about 33.4％ (on thirds) person interviewed agree with the present method to allocate by village. (Figure 17)

C. As described in the” Self-government Ordinance of feedback fund of Hsintien incinerator”, the fund should be used in the following items: 1. Matters relating to environmental or amenity; 2. issues about the enhancing the environmental quality or standard of education and life culture; 3. matters relating to health care; 4. Issues related to environmental monitoring and identification 5. Matters about public facilities management and maintenance; 6. Maters related to municipal waste disposal charge, part of the subsidy for basic household water and electricity, and subsidies for environmental protection related matters. Do you think it is reasonable or not? 1.□ Unreasonable, it should amend the law to increase the project2.□ Unreasonable, it should amend the law to decrease the project3.□ Reasonable, no need to amend the law4.□ no comment

About the answer of question” Which items is appropriate for the feedback fund?” the highest is “no comment”, the second highest is “Reasonable, no need to amend the law”. 90.6％ 34.2％ of the person interviewed say that they have no comment to the “Self-government Ordinance of feedback fund of Hsintien incinerator” . Among them there are 31.7 % think it is reasonable and no need to amend and 58.9 ％ said “no comment”. The result is consistent to the last question and reveals that the person is not satisfied but still acceptable (Figure 18)

E. Which do you think is appropriate for the use of feedback funds? 【multiple choice up to five】1.□ Improved sanitation 2.□ Environmental green landscaping 3.□ Health Insurance 4.□ Elderly care. Nursery schools 5.□ Health Care Matters 6.□ Improve the teaching environment 7.□ Watch or travel activities 8.□ Dinner and door prizes 9.□ Scholarships 10.□ School lunch 11.□ Security and fire safety 12.□ Emergency relief 13.□ Vocational training or talent 14.□ Temple construction. Refurbishment 15.□ issues of environmental pollution monitoring Identification 16.□ Public infrastructure located 17.□ others

About the answer of question” Which do you think is appropriate for the use of feedback funds?” The highest is “Health Insurance”, “Environmental green landscaping”, “Improved sanitation”, “Health Care Matters”, “Watch or travel activities”. The lowest is “Improve the teaching environment”, “Security and fire safety”, “Vocational training or talent”. From the five best items reveals that the person interviewed believes the fund should be used in the surrounding transaction.

The items “Health Insurance” and “Environmental green landscaping” was supported more than fifty percent.（Were 68.3% and 55.4%） Only 6.2％ and 6.5％ think it is appropriate to use it in the item “Improve the teaching environment” and “Security and fire safety”. The results reveal that the residents do not agree with the strategy to remove the budget on construction in the city hall to the compensation. Some other people believe that it is better to direct pay by cash. (Figure 19)

F. Which do you think is not the appropriate project for the use of feedback funds? 【multiple choice up to five】1.□ Improved sanitation 2.□ Environmental green landscaping 3.□ Health Insurance 4.□ Elderly care. Nursery schools 5.□ Health Care Matters 6.□ Improve the teaching environment 7.□ Watch or travel activities 8.□ Dinner and door prizes9.□ Scholarships 10.□ School lunch 11.□ Security and fire safety 12.□ Emergency relief 13.□ Vocational training or talent 14.□ Temple construction. Refurbishment15.□ issues of environmental pollution monitoring Identification 16.□ Public infrastructure located 17.□ others

About the answer of question” Which do you think is not appropriate for the use of feedback funds?” The highest is “Dinner and door prizes”, “Watch or travel activities”, “Temple construction. Refurbishment”, “Security and fire safety”, “Elderly care. Nursery schools”. The lowest is “issues of environmental pollution monitoring Identification”, “Health Care Matters”, and “Emergency relief”. From the five best items reveals that the person interviewed believes the fund should be used in the Surrounding transaction.

Most of the people think that it is not appropriate to use the fund in Dinner. Lottery. Travel. Temple. Fire-fighting equipment and other items. 44.4 percent of those surveyed believed that the use of the banquet and the lottery is not suitable. 5.4% of those surveyed believe that tourism activities are not appropriate. For the use of “issues of environmental pollution monitoring Identification”, “Health Care Matters”, and “Emergency relief”, they still think it its suitable. (Figure20)

4.5 Comparison of WTP values

In this study, a questionnaire survey supposes the respondents use the amount of 10,000 per year. The respondents were asked to search where they are willing to spend this amount of money. According to the results to analyze and compare them by age, sex, qualifications, residential and revenue.

The survey results of WTP for different age is shown in table 11.

According to the above results , the most important problem people want to pay money for improvement for the people age under twenty years old is : 1.Air pollution caused by the waste gas from the incinerator; 2.Waste water pollution caused by the incinerator; 3.Odor Caused by the garbage truck. ◦

The most important problem people want to pay money for improvement for the people age between twenty one to thirty years old is: 1. Waste water pollution caused by the incinerator; 2. Air pollution caused by the waste gas from the incinerator; 3. Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the people age between thirty one to forty years old is: 1. Waste water pollution caused by the incinerator; 2. Air pollution caused by the waste gas from the incinerator; 3. Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the people age between forty one to fifty years old is: 1. Waste water pollution caused by the incinerator; 2. Air pollution caused by the waste gas from the incinerator; 3.Odor Caused by the garbage truck and noise cause by the transportation of truck.

The most important problem people want to pay money for improvement for the people age above fifty years old is: 1. Waste water pollution caused by the incinerator
2. Air pollution caused by the waste gas from the incinerator; 3. The total public health insurance fees paid by the people in Hsintien city.

According to the analysis, the people are most concerned with the following problem: waste water pollution caused by the incinerator, and air pollution caused by the waste gas from the incinerator. However, the people more than forty years old are more concerned about the noise effect to the living quality. The people more than fifty years old are more concerned about the health condition for themselves and would like to pay more amount of the health insurance fee in the feedback fund.

The survey results of WTP for different age is shown in table 12. The survey results of WTP for different gender is shown in table 13.

The most important problem people want to pay money for improvement for the male residents is: 1. Waste water pollution caused by the incinerator; 2. Air pollution caused by the waste gas from the incinerator; 3. Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the female residents is: 1. Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 The total public health insurance fees paid by the people in Hsintien city和Odor Caused by the garbage truck and the overall appearance of comfort (such as chimneys, green level).

According to the analysis, the people are most concerned with the following problems: waste water pollution caused by the incinerator and air pollution caused by the waste gas from the incinerator. However, the male residents are more concerned about the odor caused by the garbage truck; the female residents are more concerned about their health condition and air pollution and the overall appearance of comfort. Since these will influence the health, so they are more willing to pay more amounts in air quality improvement and the insurance fee.

The survey results of WTP for different education is shown in table14.

According to the above results, the most important problem people want to pay money for improvement for the education under elementary school is: 1 Air pollution caused by the waste gas from the incinerator; 2 Waste water pollution caused by the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement for the people with the education of junior middle school is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement for the people with the education of senior high school is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the people with the education of college is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the people with the education of university is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the people with the education higher than master degree is: 1 Air pollution caused by the waste gas from the incinerator; 2 Waste water pollution caused by the incinerator; 3 the total public health insurance fees paid by the people in Hsintien city.

According to the analysis, the people are most concerned with the following problems: waste water pollution caused by the incinerator and air pollution caused by the waste gas from the incinerator. However, the education background under the elementary school and junior middle school are more concerned about the noise caused by the transportation of truck. Residents with the education higher than senior high school are more concerned about the improvement of air quality. Residents with the education higher than master degree are more concerned about their health condition and willing to pay more for their health insurance fee.

The survey results of WTP for different village is shown in table 15.

According to the above results , the most important problem people want to pay money for improvement in Anhe villageis : 1 Air pollution caused by the waste gas from the incinerator ; 2 Waste water pollution caused by the incinerator; 3 The total public health insurance fees paid by the people in Hsintien city

The most important problem people want to pay money for improvement in Yongan village: 1 Air pollution caused by the waste gas from the incinerator; 2 Waste water pollution caused by the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement in Hsinhe village is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement in Yongping village is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement in Gonglun village is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement in Anchang village is: 1 Air pollution caused by the waste gas from the incinerator 2 Waste water pollution caused by the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement Dean Village is: 1 Air pollution caused by the waste gas from the incinerator; 2 Waste water pollution caused by the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement in Daguan village is: 1 Air pollution caused by the waste gas from the incinerator; 2 Waste water pollution caused by the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement in Mingcheng village is: 1 Air pollution caused by the waste gas from the incinerator 2 Waste water pollution caused by the incinerator; 3 Noise cause by the transportation of truck.

The most important problem people want to pay money for improvement Hsiaocheng village is: 1Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

According to the analysis, the people are most concerned with the following problems: waste water pollution caused by the incinerator and air pollution caused by the waste gas from the incinerator because these will influence the community environmental quality. The second important item is the noise cause by the transportation of truck and the air pollution caused by the garbage truck. Since these are happened in the everyday life, so the people are willing to pay more budgets to improve the air quality.

The survey results of WTP for different income is shown in table 16.

The most important problem people want to pay money for improvement is in the following order for the resident whose monthly income below twenty thousands NT dollars: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 the total public health insurance fees paid by the people in Hsintien city.

The most important problem people want to pay money for improvement is in the following order for the resident whose monthly income between twenty thousands to forty thousands NT dollars: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 The total public health insurance fees paid by the people in Hsintien city.

The most important problem people want to pay money for improvement is in the following order for the resident whose monthly income between forty thousands to sixty thousands NT dollars is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 The impact of traffic order (such as traffic jam, speaker sound).

The most important problem people want to pay money for improvement for the resident with income level between sixty thousands to eighty thousands NT dollars is:1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator ; 3 Noise cause by the transportation of truck and odor caused by the garbage truck.

The most important problem people want to pay money for improvement for the resident with income level between eighty thousands to one hundred thousands NT dollars is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement for the resident with income level above one hundred thousands NT dollars is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 the overall appearance of comfort (such as chimneys, green level).

According to the analysis, the people are most concerned with the following problems: waste water pollution caused by the incinerator and air pollution caused by the waste gas from the incinerator because these will damage the community environmental quality. However, the people with the monthly income between twenty thousands to forty thousands NT dollars is willing to spend more budget in Hsintien city to pay more to the total public health insurance fees because they make less money and they are also care about their health condition. The people with the monthly income between forty thousands to sixty thousands NT dollars is willing to spend more budget to improve the impact of traffic order (such as traffic jam, speaker sound) because they are all working in the enterprise and have to go for work everyday, so the traffic is more important to them.

The people with the monthly income between sixty thousands to eighty thousands NT dollars is willing to spend more budget to improve the noise and air pollution problem by the garbage truck because they earn more money and they are more concern about the negative effect of their pollution, as they want to spend more money to improve the air quality. For the people with the monthly income more than one hundred thousands NT dollars, they are willing to spend more budgets to improve the overall appearance of comfort (such as chimneys, green level) because these are things related to the community quality.

The survey results of WTP for different occupation is shown in table17.

According to the above results, the most important problem people want to pay money for improvement to the student is: 1Waste water pollution caused by the incinerator; 2Air pollution caused by the waste gas from the incinerator; 3The impact of traffic order (such as traffic jam, speaker sound).

The most important problem people want to pay money for improvement to the residents working for the civil service is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 the total public health insurance fees paid by the people in Hsintien city.

The most important problem people want to pay money for improvement to the people working for the agriculture is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 the total public health insurance fees paid by the people in Hsintien city.

The most important problem people want to pay money for improvement to the people working for the industry is : 1 waste water pollution caused by the incinerator; 2 air pollution caused by the waste gas from the incinerator ; 3 the total public health insurance fees paid by the people in Hsintien city and odor caused by the garbage truck.

The most important problem people want to pay money for improvement to the people working for the commerce is: 1 Air pollution caused by the waste gas from the incinerator; 2 Waste water pollution caused by the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement to the people working in housekeeping is: 1. Waste water pollution caused by the incinerator; 2. Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement to the people working in service industry is: 1 Waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

The most important problem people want to pay money for improvement to the people working in another area is: 1 waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Odor Caused by the garbage truck.

According to the analysis, the people are most concerned with the following problems: waste water pollution caused by the incinerator and air pollution caused by the waste gas from the incinerator because these will reduce the community quality. They are also concerned about the total public health insurance fees paid by the people in Hsintien city. The students are concerned about the traffic because they fear of late for school. The industry and commerce are more concerned about the air pollution because that may influence their work. Therefore, they are willing to pay more money to improve the air quality.

The survey results of WTP for different occupation is shown in table 18. According to the above results, the most important problem people want to pay money for improvement to the marriage people is: 1. waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 the impact of traffic order (such as traffic jam, speaker sound).

The most important problem people want to pay money for improvement to the unmarried people is: 1 waste water pollution caused by the incinerator; 2 Air pollution caused by the waste gas from the incinerator; 3 Noise cause by the transportation of truck.

According to the analysis, the unmarried people are most concerned with the waste water pollution and the air pollution caused by the incinerator because that will damage the environmental quality. However, the married people also concerned about the impact of traffic order (such as traffic jam, speaker sound). The reason may be that the married people have to work in the office so they can not be late. However, the unmarried people are more concerned about the noise so that they are willing to pay more to improve this problem.

4.5 Discussion n of WTA values

Based on survey results, a great majority of people satisfied with the amount of feedback fund. The value could be regarded as the willing to accept price of the pollution effect of this incinerator (WTA)

The aomunt of compensation per person per year was shown in table 19. The WTA values of each village can ve derived from this table. The percentage distribution of satisfaction for community residents at different payment rates of feedback funds was shown in figure 21. In this figure, the x-axis is the amount of feedback fund, and the y-axis is the percentage satisfaction. By extending the line, thw WTA value can ve obtained. Therefore, the 100 % satisfaction willing to accept (WTA) value is about 3,333 NTD per person per year.

V. Conclusion

The research applied the cognitive method to estimate the WTP and WTA value of an incinerator in Northern Taiwan. In this study, we use the information of different profession, education, gender, and residential area to get the willing to pay price (WTP), and use the percentage satisfaction to calculate the willing to accept price (WTA). We also got the following three main conclusions: the compensation of the externality of pollution, the willing to accept price of the incinerator, and the items to improve the environment of the price of WTP.

From the questionnaire survey results, it reveals that the residents are most concerned about the waste water pollution caused by the incinerator and Air pollution caused by the waste gas from the incinerator. However, the residents aged above forty years old also care about noise on life quality. The residents older than fifty years old are more care about their own health and therefore they are willing to pay more on NHI costs.

The male residents are most concerned about the air pollution problems when garbage trucks go through. The female residents are more care about their health, air pollution, and the overall comfort index. Both of the pollution and overall comfort will influence our body and health condition, so they are willing to pay more health care costs to improve air quality.

Residents with the education in elementary school and junior middle school level are more concerned about the noise caused by the transportation of truck. Residents with high school level are more concerned about air condition, so they are willing to pay more costs to improve air quality. People with education level higher than graduate school do care about the health so they are willing to pay more care fees in Health-care costs. 。

Both the waste water pollution and air pollution caused by the incinerator will reduce the community environmental quality. The residents are concerned about the noise and air pollution caused by the transportation of truck is because these truck goes to everywhere in the community, so they pay more attention on this event.

Residents with monthly in 2 0,000 or less and 20, 000 to 40,000 want to pay budget in Hsintien city hall in the total public health insurance fees. This is because they comparatively focus on their health, and because they earn less money, so they want the government to help them to pay more budgets in the health insurance fee. Residents with monthly income between 40,000 to 60,000 are looking forward to pay more funds to improve the traffic order issues from the garbage truck. Because population within this range of income often has their own car for transportation, so they are afraid of delays in working hours. Residents with monthly income between 60,000 to 8 0,000 are hoping to pay budget to improve the noise and air pollution problem cause by the garbage truck. It may be the reason that the higher income people are more concerned about the negative influence from the air pollution so they want to pay more to improve the air quality. Residents with monthly income higher than 100,000 like to pay the money to improve the overall appearance of comfort issues, this maybe owing to the reason that the richer have enough funds to improve the appearance of comfort.

The married residents care about the impact of traffic order (such as traffic jam, speaker sound). Maybe because they have to go for work on time and have to go home to eat dinner with the family. However, the unmarried were more concerned about the noise when the vehicle going through. The reason may be because the single person is expecting to have a silent environment so they are willing to pay more to improve the noise problem.

Reference

1. Chen, Hsin-yi, (2007), "e Prices of Willingness to Pay of Wellness Tourism Based on Deep Sea Water Resources in Hualien County ", Travel Health Institute Taipei College of Nursing.
2. Chen, Li-chain, (2004), "Valuating and Analyzing the People for Willingness to Pay of Food Waste Recycling and Reusing-A Case Study of Kaohsiung and Taichung City", Public Affairs Management Institute, National Sun-Yat-Sen University.
3. Chen, Shu-Chun, (2003), "The Study of Residents" Cognition of the Cultural Heritage Preservation and Willingness to Pay", Leisure Management Institute, Chaoyang University.
4. Guan, Yi-Wen, (2002), "Valuing Willing to Pay of HACCP for Box Meals in Taiwan ", Institute of Applied economic, National Chung-Hsin University.
5. Huang,, Wan-Lun, (2004), "Analysis of Willingness to Pay for Local Environmental Tax at Green Island－An Application of CVM", Institute of Building and Planning , National Taiwan University.
6. Kao, Pei Ju, (2004), " The Study of the Community Residents the Cognition of the Cultural Heritage Preservation and Willingness To Pay–With the Anping Region in Tainan City as an Example.", Leisure Management Institute, Chaoyang University
7. Wu, Liang-Fan, (2005), "The Relationship among Attraction, Satisfaction and Loyalty, and Visitor's Willingness to Pay of the Chiayi International Band Festival", Tourism Management Research 6:1 2006 .06 101-123
8. Wu, Long-Kuen, (2004) , "A Study of Marketing Strategy and Consumer

Satisfaction", http://thesis.lib.nccu.edu.tw/record/#G0929230101

9. Zhan, Jin-Wei, (2007)," A Study on the Relationship between Tourists' Perception of Hot Spring Resource Conservation and their Willingness To Pay a User's Fee ", Institute of land management, Feng-Chia University.
10. Lin, Hsien-ku, (2000)," The Feedback Mechanism in Taiwan's Urban Land Use Rezoning System：The Case of Taichung City ". Institute of architecture and urban design, Feng-Chia University.
11. Hsu, Wen-Hung, (2007), "Case Study of Maioli City about the Cash Rewards on B.O.T Incineration Factory." Institute of Environmental Engineering, National Chung-Hsin University.
12. Lin, Wen-yuan, (Lin，2004) "Case Study of Compensation Institution of a Municipal Solid Waste Incineration in Lucao, Chiayi County." Institute of Environmental Management, Nan-Hua University.
13. Hung, Chun-Hsiang, (2007) "Use Taipei Songshan Airport as an example for the study of effect of implementing the airport compensation." Institute of architecture and urban design , Chaoyang University,
14. Chen, Wei-cheng, (2006)," Case Study based on the Contribution Usage of the Kung-Liao Nuclear Power Plant for the Research of the Policy-making Mechanism involving Environmental Pollution:.", Department of Public Affairs, Fo-Guang University.

Table 1 The amount of compensation budget Unit：1000 dollar

construction of monetary incentives	facility feedback
10,000.000	186,790.000

Table 2 the allocation ratio of feedback fund to the different village.

Village	population	Distribution ratio
Taiping village	3343	3.5%
Meicheng village	2859	3.5%
Dingcheng village	1787	3.5%
Hsiacheng village	2502	3.5%
Gonglun village	10016	3.5%
Anchang village	4755	5%
Dean village	6601	18%
Shuangcheng village	6092	5%
Riihsing village	5892	3.5%
Chaicheng village	8395	3.5%
Anhe village	6295	3.5%
Yongping village	5729	3.5%
Yong-an village	5370	3.5%
Hsinhe village	4365	3.5%
Tutan village	974	1.75%
Huacheng village	2322	1.75%
Mingcheng village	3392	5%
Hsiaocheng village	3713	5%
Shiangpo village	6382	5%
Meigue village	5966	5%
Jishiang village	4605	5%
Daguan village	3492	5%
total	104,847	100%

Table 3 population in the area where Questionnairs sent out

Questionnairs send out area	population
Gonglun Village	10016
Anchang Village	4755
Dean Village	6601
Anhe village	6295
Yongping village	5729
Yong-an Village	5370

Hsinhe village	4365
Mingcheng Village	3392
Hsiaocheng Village	3713
Daguan Village	3492
total	50336

Table 4 questionnair recovery rate of this survey

Village	Number of questionnaires sent out	Number of households returned questionnaires	Recovery rate %
Anhe villageAnhe village	50	40	40
Yong-an Village	33	32	97
Hsinhe Village	92	77	78
Yongping village	66	60	89
Gonglun village	33	32	97
Anchang Village	33	32	94
Dean Village	33	30	91
Daguan Village	40	39	98
Mingcheng Village	85	38	52
Hsiaocheng Village	35	35	100

Table 5 Gender distribution table for the person interviewed

Gender	Number
Male	253
Female	162
Total	415

Table 6 Age distribution table for the person interviewed

Age	population
Under 20	20
21 to 30	69
31 to 40	135
41 to 50	105
Above 51	86
total	415

Table 7 Place of residence distribution of the number issued for feedback compenssation

Place of residence	Number issued
Anhe village	50
Yong-an Village	33
Hsinhe Village	92
Yongping village	66
Gonglun village	33
Anchang Village	33
De-an Village	33
Daguan Village	40
Mingcheng Village	85
Hsiaocheng Village	35
total	500

Table 8 Table of population by education for the person interviewed

Education Level	Number
Primary school	19
Junior	18
High School (Vocational)	72
College	103
University	100
Institute	103
Total	415

Table 9 Marital status for the person interviewed

Marital Status	Number
Unmarried	79
Married	336
total	415

Table 10 Occupational allocation table for the person interviewed

Profession	number
Student	24
Military, civil service	55
Forestry, fishery and livestock farming	21
Industry	55

Business	24
House keeping	73
Services	133
Other	30
total	415

Table 11 Monthly income distribution tables fot the person interviewed

Monthly income	Number
Below 20 thousand	135
20 thousand -40 thousand	228
40 thousand -60 thousand	45
60 thousand -80 thousand	4 1
80 thousand -100 thousand	2
Greater than 100 thousand	1 0

Table 12 The survey results of WTP for different age

Comparison of WTP for different ages					
externalities / age	Under 20	21 to 30	31 to 40	41 to 50	Above 51
The total public health insurance fees paid by the people in Hsintien city	1200	1278	750	1100	1750
Air pollution caused by the waste gas from the incinerator	1800	1667	2000	1600	2000
Odor Caused by the garbage truck	1600	1528	1750	1400	1250
The overall appearance of comfort (such as chimneys, green level)	1100	1334	1250	1200	1000
Noise cause by the transportation of truck	1200	1167	1000	1400	1000
The impact of traffic order (such as traffic jam, speaker sound)	1300	1278	1000	1100	1250
Waste water pollution caused by the incinerator	1800	1694	2000	1700	2000
total	10000	9946	9750	9500	10250

unit : NT dollar/year/person

Table 13 The survey results of WTP for different gender

Comparison of WTP		
externality / gender	male	female
The total public health insurance fees paid by the people in Hsintien city	1282	1455

Air pollution caused by the waste gas from the incinerator	1750	1682
Odor Caused by the garbage truck	1344	1455
The overall appearance of comfort (such as chimneys, green level)	1125	1455
Noise cause by the transportation of truck	1219	1136
The impact of traffic order (such as traffic jam, speaker sound)	1250	1136
Waste water pollution caused by the incinerator	1844	1773
total	9814	10092

Table 14 The survey results of WTP for different education

Comparison of WTP for different education						
education / externalities	Elementary school	Junior	School (Vocational	college	university	institute
The total public health insurance fees paid by the people in Hsintien city	1105	1235	1156	1320	1200	1432
Air pollution caused by the waste gas from the incinerator	1763	1780	1820	1748	1879	1950
Odor Caused by the garbage truck	1080	1038	1221	1398	1425	1378
The overall appearance of comfort (such as chimneys, green level)	1069	1029	1125	1009	1308	1352
Noise cause by the transportation of truck	1452	1326	1219	1179	1290	1324
The impact of traffic order (such as traffic jam, speaker sound)	1312	1193	1136	1230	1328	1245
Waste water pollution caused by the incinerator	1689	1899	1844	1895	1885	1823
total	9470	9536	9521	9779	10315	10504

Table 15 The survey results of WTP for different village

Comparison of WTP for different village					
village / externalities	Anhe village	Yong-an Village	Hsinhe village	Yongping village	Gonglun village
The total public health insurance fees paid by the people in Hsintien city	1312	1230	1140	1230	1106
Air pollution caused by the waste gas from the incinerator	1844	1895	1879	1689	1780
Odor Caused by the garbage truck	1221	1290	1362	1378	1250
The overall appearance of comfort (such as chimneys, green level)	1095	1135	1189	1254	1265
Noise cause by the transportation of truck	1080	1362	1250	1398	1290
The impact of traffic order (such as traffic jam, speaker sound)	1230	1245	1354	1193	1142
Waste water pollution caused by the incinerator	1785	1876	1880	1763	1852
total	9567	10033	10054	9905	9685

Comparison of WTP for different village					
village / externalitite	Anchang Village	Dean Village	Daguan Village	Mingcheng Village	Hsiaocheng Village
The total public health insurance fees paid by the people in Hsintien city	1240	1136	1250	1150	1210
Air pollution caused by the waste gas from the incinerator	1823	1885	1950	1899	1820
Odor Caused by the garbage truck	1080	1398	1345	1195	1205
The overall appearance of comfort (such as chimneys, green level)	1211	1179	1320	1120	1192
Noise cause by the transportation of truck	1540	1378	1221	1250	1195
The impact of traffic order (such as traffic jam, speaker sound)	1229	1328	1327	1248	1169
Waste water pollution caused by the incinerator	1732	1721	1848	1748	1852
total	9855	10025	10261	9610	9643

Table 16 The survey results of WTP for different income

Comparison of WTP for different income						
income / externalities	below 20000	20000-40000	40000-60000	60000-80000	80000-100000	Above 100000
The total public health insurance fees paid by the people in Hsintien city	1178	1387	1280	1281	1359	1349
Air pollution caused by the waste gas from the incinerator	1486	1452	1568	1672	1689	1769
Odor Caused by the garbage truck	1053	1148	1183	1349	1459	1345
The overall appearance of comfort (such as chimneys, green level)	1012	1049	1049	1125	1296	1387
Noise cause by the transportation of truck	1130	1173	1124	1349	1240	1346
The impact of traffic order (such as traffic jam, speaker sound)	1145	1199	1368	1257	1347	1249
Waste water pollution caused by the incinerator	1689	1767	1876	1897	1989	1968
total	8693	9175	9448	9930	10379	10413

Table 17 The survey results of WTP for different occupation

Comparison of WTP for different occupation								
occupation / externalities	student	Civil service	agricture	industry	commercial	House keeping	service	others
The total public health insurance fees paid by the people in Hsintien city	1346	1471	1487	1359	1245	1269	1354	1245
Air pollution caused by the waste gas from the incinerator	1678	1790	1751	1689	1836	1783	1733	1796
Odor Caused by the garbage truck	1346	1351	1423	1359	1376	1469	1450	1536
The overall appearance of comfort (such as chimneys, green level)	1180	1189	1234	1136	1285	1249	1311	1420
Noise cause by the transportation of truck	1259	1396	1258	1206	1309	1145	1201	1369
The impact of traffic order (such as traffic jam, speaker sound)	1357	1246	1287	1310	1349	1278	1349	1470
Waste water pollution caused by the incinerator	1798	1879	1969	1895	1761	1879	1861	1871
total	9964	10322	10409	9954	10161	10072	10259	10707

Table 18 The survey results of WTP for marriage status

Comparison of WTP for different marriage status		
marriage / externalities	Married	Unmarried
The total public health insurance fees paid by the people in Hsintien city	1278	1039
Air pollution caused by the waste gas from the incinerator	1746	1723
Odor Caused by the garbage truck	1010	1280
The overall appearance of comfort (such as chimneys, green level)	1179	1249
Noise cause by the transportation of truck	1048	1520
The impact of traffic order (such as traffic jam, speaker sound)	1548	1027
Waste water pollution caused by the incinerator	1876	1848
total	9685	9686

Table 19 The survey results of WTA for different districts

villages	amount	Percentage %	Number	Aomunt of compensation per person per year
Gonglun	20952000	3.5%	10016	73
Anchang	20952000	5%	4755	220
DeAn	20952000	18%	6601	571
Anhe	20952000	3.5%	6295	117
Yongping	20952000	3.5%	5729	128
Yongan	20952000	3.5%	5370	137
Hsinhe	20952000	3.5%	4365	168
Mingcheng	20952000	5%	3392	309
Hsiaocheng	20952000	5%	3713	282
Daguan	20952000	5%	3492	300

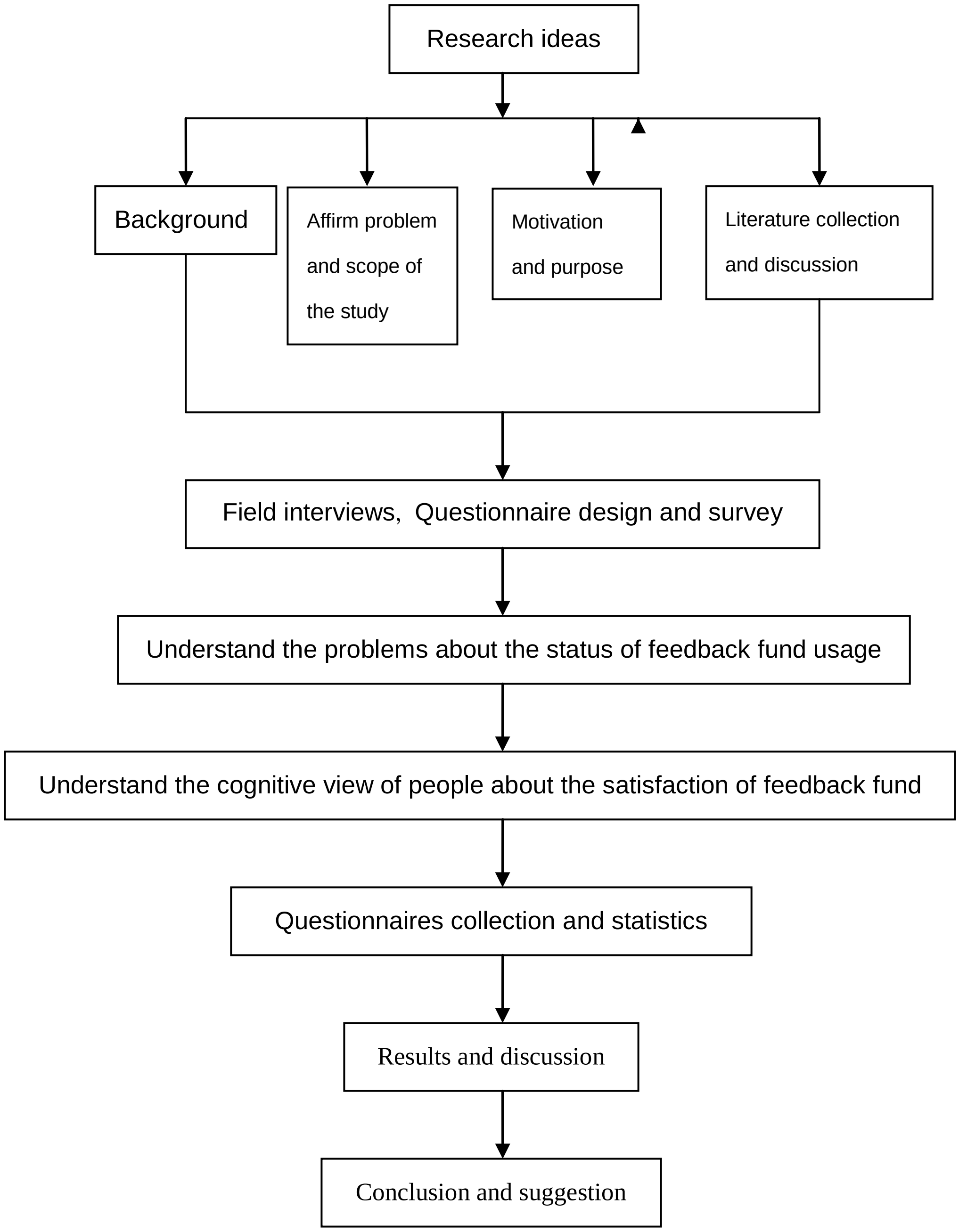


Figure1 Research Flowchart

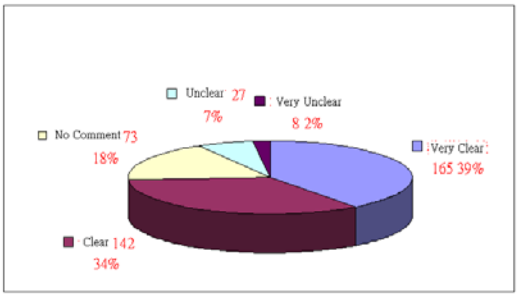


Figure 2 Survey results for the understanding of feedback fund of the incinerator

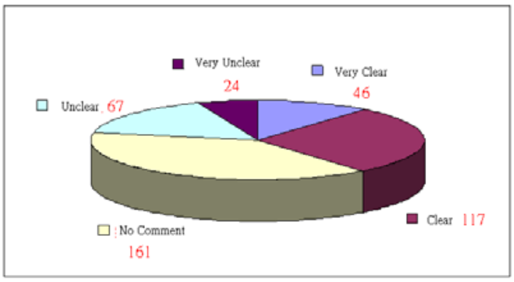


Figure 3 Survey results for the understanding of feedback compensation fund usage

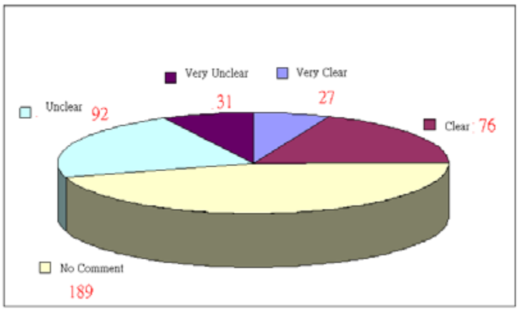


Figure 4 Survey results for the question “Do you know that the process of the usage, distribution, management, decision, is through the following procedure?”

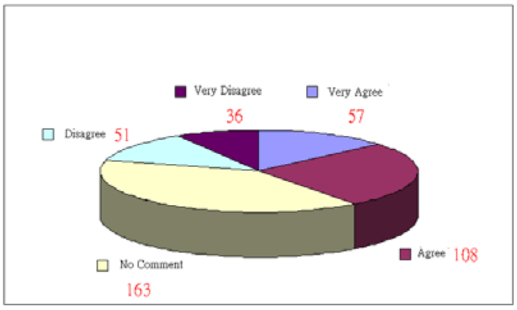


Figure 5 Survey results for the question “Do you agree with the present decision making process of the usage of feedback compensation?”

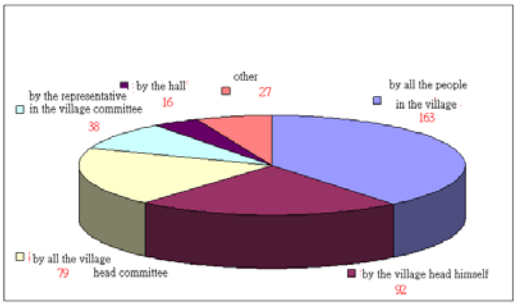


Figure 6 Survey results for the question “Which do you think is the best for the usage of feedback compensation in the village”

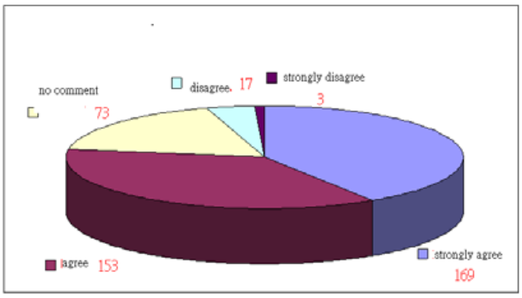


Figure 7 Survey results for the question “Do you agree to participate in the decision making process of the feedback fund usage of your village?”

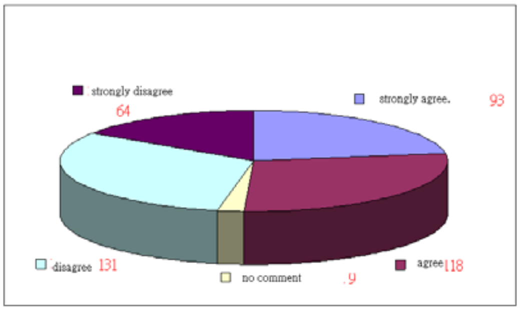


Figure 8 Survey results for the question “Hsintien incinerator has operated for fifteen years, do you agree that it does not contaminate?”

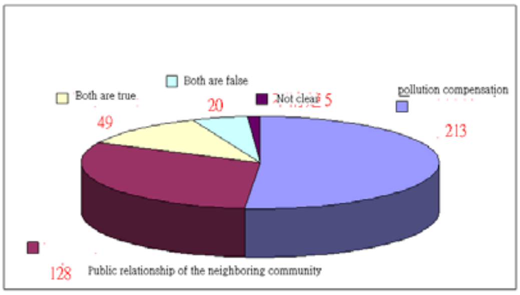


Figure 9 Survey results for the question “How do you think about intension of such funds (Incinerator feedback fund)?”

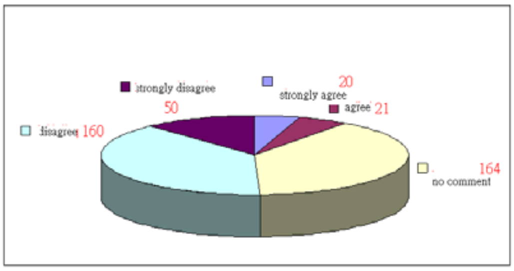


Figure 10 Survey results for the question “Do you think that it is because of the feedback compensation so that you will not against the install of this incinerator?”

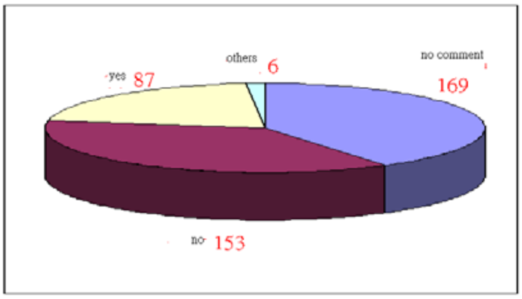


Figure 11 Survey results for the question “Do you agree that the feedback fund will influence the residents’ intension to move into or out of the “compensation area”?

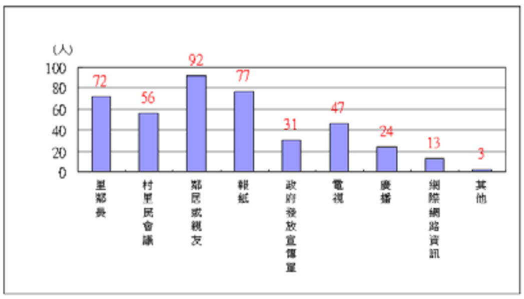


Figure 12 Survey results for the question “Where do you know the information about the feedback compensation?”

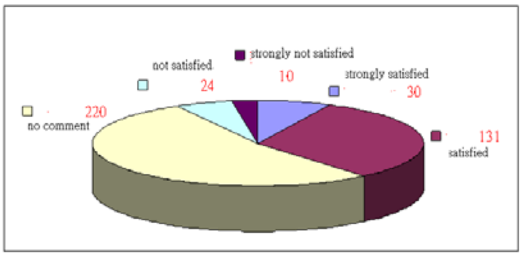


Figure 13 Survey results for the question “Do you satisfied with the amount of feedback compensation for your village?”

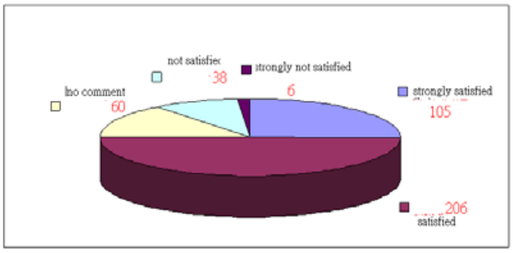


Figure 14 Survey results for the question “Do you satisfied with the present usage of the feedback fund in your village?”

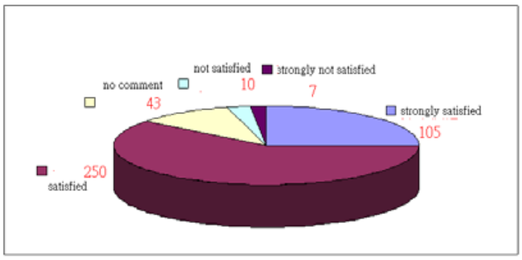


Figure 15 Survey results for the question “Do you satisfied with the amount of feedback compensation for your basic utilities?”

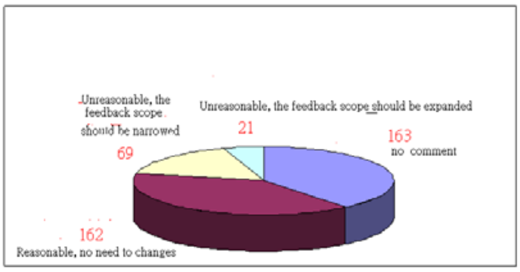


Figure 16 Survey results for the question “As described in the “Self-government Ordinance

of feedback fund of Hsintien incinerator", the area for compensation area is limited to the local area near the incinerator. Do you thick it is reasonable?"

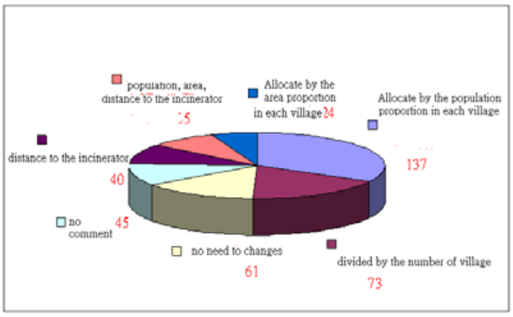


Figure 17 Survey results for the question "Which do you think is the better way for the feedback fund allocation level?"

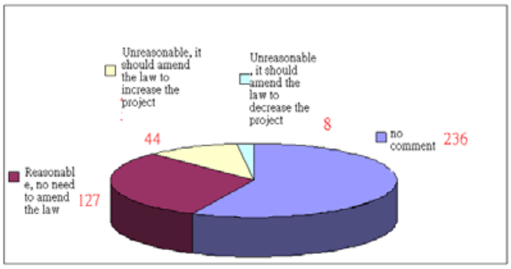


Figure 18 Survey results for the question "Which items is appropriate for the feedback fund?"

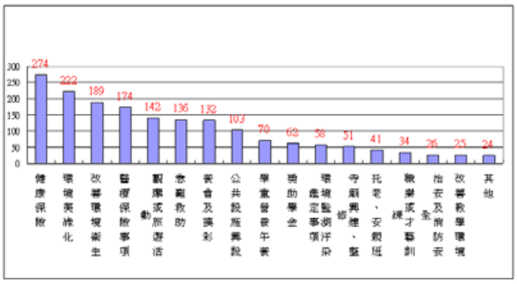


Figure 19 Survey results for the question "Which do you think is appropriate for the use of feedback funds?"

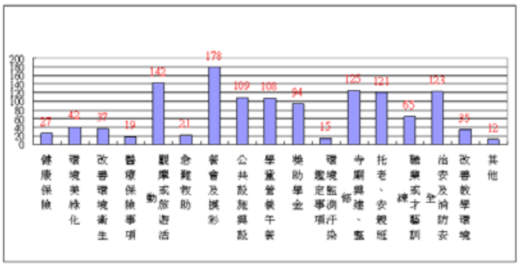


Figure 20 Survey results for the question "Which do you think is not appropriate for the use of feedback funds?"

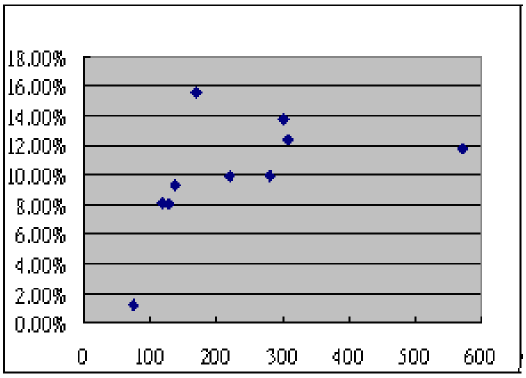


Figure 21 The percentage distribution of satisfaction for community residents at different payment rates of feedback funds

Note：The x-axis is the amount of feedback fund, and the y-axis is the percentage satisfaction，The 100% satisfaction willing to accept (WTA)is about 3333 NTD per person per year.

Economic Analysis of the Introductions of Biogas Plant to Japanese Dairy Farming Households

Tatsuo Suwa *

10th July 2010

*Hokkaido University Public Policy School, Kita9. Nishi7. Kita-Ku. Sapporo. 060-0809. Japan, E-mail: suwa@hops.hokudai.ac.jp

1 Introduction

Recently, Japanese government is promoting introductions of renewable energy to replace fossil fuel and reduce CO_2 emission. Biomass is one of the sources for the renewable energy. Among the biomass, this study focuses on livestock excreta generated by Japanese dairy farming area. Biogas plant (BGP) has been developed to dispose of livestock excreta emitted by dairy farming. It makes Biogas from animal excreta by methane fermentation. Biogas is mainly composed of Methane and can be utilized as a fuel for electric power generation. This generation process is recognized as "Carbon Neutral". However according to Matsuda(2009) BGP is still unfamiliar in Japan, compared to European Countries such as Germany.

This study focus on a dairy farming household in Hokkaido region which is northern area of Japan, because in the region dairy farming is carried out most intensively in Japan. Hokkaido has the half of Japanese total dairy cow. It is known that a dairy cow emits manure about 70 kg per day. It means that a volume of manure is emitted in dairy land. Therefore, deterioration of water quality in local river and lake are concerned in Hokkaido. To address this issue, "Act on the Appropriate Treatment and Promotion of Utilization of Livestock Manure" was enacted in 1999. The dairy farmers are obliged to build a concrete-covered compost depot and to hold livestock manure in it. BGP operation has a positive effect also on this issue, because it converts livestock manure to digested slurry which has no smell.

According to Matsuda (2009)[8], only a few hundred of BGP have been introduced in Japan, while about 4,000 in Germany. Matsuda(2009) insists that the popularity of BGP in Germany depends on feed in tariff for the power generated by BGP. In Germany, BGP whose output less than 150kw can sell its power for about 35 ¥. Moreover, the price is guaranteed for 20 years though the level is decrease by 1 % per year. Therefore, it is quite obvious that the diffusion of the BGP depends on the price lever of generated power and resulting profitability. This study investigates the possibility of BGP diffusion in japan, by considering economic condition such as price level of the generated power.

In Japan, Feed-in Tariff mechanism has been adopted for household solar power generation since last year. The possibility in introduction of Feed-in Tariff for electricity generation by BGP could be also considered. Thus far, many studies in terms of BGP profitability have been done in Japan. Some of them investigate break-even calculation pertaining to the rate of electricity generated in BGP. Ishikawa et al.(2005)[4] investigates the relation between power selling price and redemption period of the plant. This paper shows that even though 90 % of initial cost is subsided; the power selling price must be more than 100 ¥/kwh in order to pay off for 30 year. However, they also indicate that if the revenue from receiving supplementary materials can be assured, BGP is paid off for 20 years with 37 ¥/kwh and subsidy of 75% initial cost. Ono and Ugawa(2005)[13] compare the profitability between different specification of dairy farming operation. They show that BGP become profitable when BGP deals only with liquid cattle manure and its scale of operation is doubled. These existing studies are based a close observation for the actual BGP management.

However, most of such studies are based on the simple comparison between cost and revenues. These studies do not take account for change in dairy production induced by the change in price of power generated by BGP. It is very possible that depending on the rate dairy farming household changes the amount of inputs such labor and cow and the resulting quantity of output.

Meanwhile, the "Household Model" has been developed in the study field of development economics and agricultural economics, in order to investigate the behavior of a peasant(see Sadoulet and De janvry (1995))[15] and Kurosaki(2002)[7]). This model gives the microeconomic foundation for the analysis of farming households and assumes that they is not only profit maximizing agents but also consumers who maximize their own utility. In literature of the model related to Japanese agriculture, Sonoda and Maruyama(1999)[16] apply this model to Japanese rice farmers. The application of the household model to the dairy household looks quite appropriate, because the most of them still rely on family labor. However, we can find few studies which investigate Japanese dairy farming with the household model. Accordingly, this study applies the household model, to investigate technology of dairy farming and preference of households engaged in it. By the household model, structural parameters of production and utility function are estimated. Furthermore, BGP production functions that represent the relation between the amount of generated biogas and input for it are estimated in this study.

Iwamoto et al.(1999)[5] also implements simulation analysis for dairy farming operation. They investigates the income change of Hokkaido dairy household induced by regulation policy which tightens the stocking density of cattle. However, they do not take account of the consumer aspect of dairy household. This study also attempt to by a simulation analysis related to the Feed in Tariff for generated power in BGP, using the parameters estimated in the household model.

This paper is comprised of the four sections. The next section details the specification of the economic model that represents dairy farming household. The third section describes the details of the employed data and the econometric model utilized in this study. The fourth section presents policy implications that be derived from simulation analysis.

2 Model

In this study, the household model developed in agricultural economics or development economics (see Sadoulet and De janvry (1995))[15] is applied to investigate technology of dairy farming and preference of households engaged in it. In this model, farming household is regarded as not only a consumer maximizing own utility also producer maximizing profit. Further, Kurosaki(2002)[7] shows that the household model is sorted to separable model and non-separable model. If markets for all input and output appear to exist, the farm production is independent from their consumption behavior. This case corresponds to separable model. However if market for one or some of input (such as labor) is absent, the farm households must provide it by themselves. Kurosaki(2002) refer to this case as non-separable model.

Many studies applies the non-separable household model into analysis of subsistence farming household in developing countries. In addition, Sonoda and Maruyana(1999) [16] adopt this model to Japanese rice framing households, because they appears to face constrained off-farm employment. They implements structural estimation of utility and production function and comparative static analysis. They shows that the increase of rice price induces the reduction of labor input and resulting rice production by the internal wage rate change. Thus far, few studies have applied non-separable household model into Japanese farm.

In general, raw milk production must go on all the time , because dairy cows provide raw milk every day. In most of dairy farming household in Hokkaido rely only on their own family labor [1] These facts imply that the Hokkaido dairy farming household is not only manager or employer of raw milk production, but also employee of the industry. In this case, optimal labor force input for dairy production is no longer separable to their preference as a consumer. With these reason, this study applies the non-separable household model to the dairy household in Hokkaido. The utility maximization problem for non-separable dairy household with BGP is described as follows.

2.1 The Household Model

Considering the dual nature of dairy households, non-separable household model is adopted to represent their behavior. Following utility maximization problem is assumed for dairy household in Hokkaido region.

$$\mathbf{Max}\, U(C,Z) \tag{1}$$

$$s.t\ \ P_C C = \pi_Y + \pi_G,$$

$$\pi_Y = P_Y Y - P_M M - P_S S - P_K K - P_F F,\ \pi_G = P_G G - P_B B$$

$$Y = f_Y(M,S,F,L),\ G = f_G(M,B),\ \ B \geq 0$$

$$L + Z = T$$

where C is household consumption, P_C is its price, Z is leisure time, π_Y is profit of dairy farming, π_G is profit from biogs plant, Y is the amount of milk production, P_Y is its price, $f_Y(\cdot)$ is production function of milk, M is the number of dairy cows, S,K is building for dairy production, F is other input, P_M,P_S,P_K,P_F are price of inputs respectively, $L$is labor hour,G is the amount of generated biogas, P_G is its price, $f_G(\cdot)$ is production function of biogas, B is P_B is its price, T is initial endowment of time.

This model means that 1) the utility of dairy household depend on their consumption and leisure, 3)the consumption is financed only by dairy farming and BGP, 3) labor force for fairy farming is employed only from their own household, 4)The output of BGP depend only on the number of dairy cows and the scale of fermenter. Moreover, the possibility of corner solution

[1]Dairy helper has been introduced since in these days, in order to give dairy household vacation. However, according to Hokkaido government (2004)[3] the ann''al average time for dairy helper use is only 14.9 days

of BGP operation is also considered. The utility maximization problem of dairy household provides following Lagrangian.

$$
\begin{gathered}
L = U(C,Z) \qquad (2)\\
+\lambda\{(P_Y f_Y(M,S,K,F,L) - P_M M - P_S S - P_K K - P_F F) + (P_G f_G(M,B) - P_B B) - PcC\}\\
+\mu(T - L - Z)\\
+\phi B
\end{gathered}
$$

Differentiating the (2) with respect to choice variable of dairy household, following first order conditions are derived.

$$
\begin{gathered}
\frac{\partial L}{\partial C} = \frac{\partial U}{\partial C} - P_C\lambda = 0\\
\frac{\partial L}{\partial Z} = \frac{\partial U}{\partial Z} - \mu = 0 \qquad (3)\\
\frac{\partial L}{\partial M} = \lambda(P_Y\frac{\partial f_Y}{\partial M} - P_M + P_G\frac{\partial f_G}{\partial M}) = 0\\
\frac{\partial L}{\partial S} = \lambda(P_Y\frac{\partial f_Y}{\partial S} - P_S) = 0\\
\frac{\partial L}{\partial K} = \lambda(P_Y\frac{\partial f_Y}{\partial K} - P_F) = 0\\
\frac{\partial L}{\partial F} = \lambda(P_Y\frac{\partial f_Y}{\partial F} - P_F) = 0\\
\frac{\partial L}{\partial L} = \lambda(P_Y\frac{\partial f_Y}{\partial L}) - \mu = 0 \qquad (4)\\
\frac{\partial L}{\partial \lambda} = (P_Y f_Y(M,S,K,F,L) - P_M M - P_S S - P_K K - P_F F) + (P_G f_G(B,M) - P_B B) - P_c C = 0\\
\frac{\partial L}{\partial \mu} = T - L - Z = 0\\
\frac{\partial L}{\partial B}\cdot B = \{\lambda(P_G\frac{\partial f_G}{\partial B} - P_B)\}\cdot B = 0,\ B \geq 0
\end{gathered}
$$

3 The Estimation of Household Model

The household model analysis specifies the utility function of the farming households and their production function. Next by using actual data for farming household, it estimates the parameter of both functions under the assumption of utility maximization. Further, based on the economic model and estimated parameters, analysis for some policy such as intervention price could be implemented.

3.1 Data

In this study, Production Cost of Farm and Livestock Products (PCFLP) (1997-2009) [10] is employed published by Ministry of Agriculture, Forestry and Fisheries, Japan is employed for econometric analysis. These statistics contains the data related to the production and consumption of dairy farming household. They show the date for whole of Japan, this study use the data only for Hokkaido region. Price Indies of Commodities in Rural Areas(PICRA) [9] and Annual Report for Consumer Price Index(ARCP) [11] are utilized to determine price level of dairy input and consumption of dairy household. The data gathered from these statistics are arranged suitable for application for econometric analysis. Table 1 presents variables used in this study and their source. Table 2 describes mean and standard deviation of them.

3.2 Econometric Model

Because BGP operation is still uncommon, PCFLP does not include the data for BGP operation. Therefore, BGP operation in utility maximization problem (1) is ignored in the procedure for parameter estimations. Eventually, the following economic model is considered in the estimation process.

$$\textbf{Max}\ U(C,Z)$$
$$s.t\ \ P_C C = \pi,\ \pi = P_Y Y - P_M M - P_S S - P_k K - P_F F$$
$$Y = f(M,S,K,F,L),\ L+Z=T$$

3.2.1 Estimation of the Dairy Farming Production Function

So far, production functions that represent dairy production has been developed in some studies. Egaitsu(2002)[2] present BC-M procedure for dairy production. He divided dairy prosecution into Biology-Chemistry (BC) procedure in which labor and artificial are input and mechanics (M) procedure in which dairy cow and feedstuffs are employed. In this model both procedure are assumed to be complementary to each other. While this procedure is very suitable for actual dairy production, the assumption of perfect complementrarity is very restrictive and makes parameter estimation complicated. Therefore, according to Sonoda(2008)[11], this study employs trans-log production function [2] which has flexibility in terms of substitution across input factors. The actual function is defined as follows,

$$\begin{aligned}
\log Y = \beta_0 + \beta_1 \log M + \beta_2 \log S + \beta_3 \log K + \beta_4 \log F + \beta_5 \log L \qquad (5)\\
+\frac{1}{2}\beta_6(\log M)^2 + \frac{1}{2}\beta_7(\log S)^2 + \frac{1}{2}\beta_8(\log K)^2 + \frac{1}{2}\beta_9(\log F)^2 + \frac{1}{2}\beta_{10}(\log L)^2\\
+\beta_{11}\log M \log S + \beta_{12}\log M \log K + \beta_{13}\log M \log F + \beta_{14}\log M \log L\\
+\beta_{15}\log S \log K + \beta_{16}\log S \log F + \beta_{17}\log S \log L\\
+\beta_{18}\log K \log F + \beta_{19}\log K \log L + \beta_{20}\log F \log L\\
+\beta_{21}SD1 + \beta_{22}SD2 + \beta_{23}SD3 + \beta_{24}TT + \varepsilon_1
\end{aligned}$$

likewise Sonoda and Maruyama(1999), scale dummies and time trend dummies are also added into the production function. The first order conditions related to inputs, M, S, K, F are arranged to following share equations.

$$\frac{P_M M}{P_Y Y} = \beta_1 + \beta_6 \log M + \beta_{11}\log S + \beta_{12}\log K + \beta_{13}\log F + \beta_{14}\log L + \varepsilon_2 \qquad (6)$$

$$\frac{P_S S}{P_Y Y} = \beta_2 + \beta_7 \log S + \beta_{11}\log M + \beta_{15}\log K + \beta_{16}\log F + \beta_{17}\log L + \varepsilon_3 \qquad (7)$$

$$\frac{P_K K}{P_Y Y} = \beta_3 + \beta_8 \log K + \beta_{12}\log M + \beta_{15}\log S + \beta_{18}\log F + \beta_{19}\log L + \varepsilon_4 \qquad (8)$$

$$\frac{P_F F}{P_Y Y} = \beta_4 + \beta_9 \log F + \beta_{13}\log M + \beta_{16}\log S + \beta_{18}\log K + \beta_{20}\log L + \varepsilon_5 \qquad (9)$$

In this model, we have to keep in mind that we cannot estimate share equation of L. Although L is also input of dairy farming production, the wage rate is not observed, because L is provided only in household and consequently the share equation of L is not formulated unlike other inputs. Error terms $\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4, \varepsilon_5)'$ are assumed to have zero mean and multivariate normal distribution. In this estimation process and $\log M$,$\log S$,$\log F$,$\log L$ are treated as endogenous variables. Employing $SD1, SD2, SD3, TT, hnum, P_c, P_y, P_m, P_, sP_k, P_f$ instruments, the parameters of the original production function (5) and five share equations (6), (7), (8), (9) are

[2]Toki et al.(2008) [14] investigates cost structure of dairy production of Hokkaido, by using translog cost function. However, they do not consider utility maximization of dairy household unlike this study.

estimated by three stage least square method, in this study. 3SLS command in TSP version 5.1 is employed for the actual estimation procedure. Table 4 presents the estimation result of the production function.

3.2.2 Estimation of the Utility Function

The Stone-Geary utility function is applied to represent the preference for the dairy household, just like Sonoda and Maruyama(1999).

$$U(C,Z) = b_1 \log(C - a_1) + b_2 \log(Z - a_2)$$

Imposing homogenous degree one, $b_1 + b_2$ is set to one. According to Sonoda and Maruyama(1999), a_1, a_2 are assumed to depend on the number of household $Hnum$ as follows.

$$a_1 = a_{10} + a_{11} Hnum$$
$$a_2 = a_{20} + a_{21} Hnum$$

From first order condition (3) and (4), we obtain following equation.

$$P_C \cdot \frac{\partial U / \partial Z}{\partial U / \partial C} = P_Y \cdot \frac{\partial f}{\partial L}$$

The left hand side corresponds to marginal benefit of leisure, whereas the right hand side the value of marginal product of household labor. This equation precisely implies equilibrium of internal labor market in dairy household. In other words, dairy production corresponds with labor supply(leisure demand) must be coincide with labor demand for dairy production under internal wage rate w^*. Invoking the estimation result of production function, w^* is calculated as follows[3].

$$w^* = P_Y \cdot \frac{\partial f}{\partial L}$$
$$= \frac{p_Y Y}{L} \hat{\beta_5} + \hat{\beta_1} 0 \log L + \hat{\beta_{17}} \log M + \hat{\beta_{19}} \log S + \hat{\beta_{20}} \log F$$

Here, we consider full income (FI) of dairy household defined as,

$$FI = \pi + w^* T * Lnum.$$

[3]This procedure is introduced in Sonoda and Maruyama(1999). Kurosaka(2002) shows the this approach does not employ information of household preference and consequently is not consistent to the original model.

where T is endowment of time. Using this w^* and FI, Stone-Geary specification yields following linear expenditure system(LES).

$$w^*Z = (a_{20} + a_{21}Hnum)w^* + b_2(FI - (a_{10} + a_{11}Hnum)P_C - (a_{20} + a_{21}Hnum)\ w^*)$$

This regression equation is estimated by two stage least square method. In the estimation, w^* is treated as endogenous variable. Identical instrumental variables to the estimation of production function are also employed here. The estimation is implemented by *LSQ* command of TSP version 5.1. The estimation result is shown is Table 5.

3.2.3 Biogas Plant

The BGP production function is also estimated[4]. Nogyo doboku Shinbunsya (2002) [12] provides the information in detail about 13 BGP actually operated in Hokkaido. It includes the cubic capacity of biogas fermenter, the number of dairy cows, the initial and annual running cost, the amount of generated power, power conversion efficiency of the plant, methane concentration of biogas and so on. Table 3 shows the descriptive statistics of the 13 BGP[5]. The dependent variable of the BGP production function is the generated amount of biogas. This study employs the number of dairy cows and the cubic capacity of biogas fermenter as the explanatory variable of the function. The production function is specified also as translog form.

$$\log G = \gamma_0 + \gamma_1 \log B + \gamma_2 \log M + \frac{1}{2}\ \gamma_3 (\log B)^2 + \frac{1}{2}\ \gamma_4 (\log M)^2 + \gamma_5 \log B \log M + \varepsilon$$

Using the 13 sample of BGP in Hokkaido, the parameters of this equation is estimated by ordinary least square method, using *OLSQ* command of TSP version 5.1. Table 6 shows the estimation results of the BGP production function.

[4] Umetsu et al. also implement regression analysis about relation between generated power and plant scale.

[5] This study postulates that in-service period of BGP is 15 years. Consequently, the annual expenditure for BGP consists of sum of annual running cost and fifteenth initial cost.

3.3 The Estimation Results

4 Policy Simulation

In previous section, structural parameters are estimated by systems of regression equations. The result shows characteristics of technology in the dairy farming production in Hokkaido area. Sonoda and Maruyama (1999) also applied non-separable household model into Japanese rice farming household. They showed very counter-intuitive implication that increases in rice price may induce reduction of their labor supply via internal wage effect. In a similar manner, employing the estimated parameters, this study investigates how dairy farming household response to the change in rate for generated electricity in BSP, by employing estimated parameters. This study also attempt to solve optimal level of each inputs of dairy farming under the change in the rate. The simulation result will show some policy implication for Feed-in-tariff policy for BGP.

4.1 Feed in Tariff

In these days, Feed-in-tariff mechanism has been introduced to promote renewable energy use. Japanese government also formulate the Renewable Portfolio Standard(RPS) in 2002. Power companies are obliged to utilize the renewable energy in certain ratio of total amount of electricity they sell. Furthermore, the photovoltaic power generated in general household are purchased 48¥(kWh) since 2009[1]. The energy generated by BGP is also included in renewable energy designated by the low. Therefore, it is important to consider the Feed-in-tariff for Japanese BGP power and to predict resulting outcome in dairy farming operation in Hokkaido region.

4.2 Research in Progress

Solving following simultaneous equations, we will obtain the solutions of choice variables for optimal dairy production. In this equations, variables to be solved are $C, Z, M, S, K, F, L, B, Y, G$.

$$\log Y = \hat{\beta}_0 + \hat{\beta}_1 \log M + \hat{\beta}_2 \log S + \hat{\beta}_3 \log K + \hat{\beta}_4 \log F + \hat{\beta}_5 \log L$$

$$+\frac{1}{2}\,\hat{\beta}_6(\log M)^2 + \frac{1}{2}\,\hat{\beta}_7(\log S)^2 + \frac{1}{2}\,\hat{\beta}_8(\log K)^2 + \frac{1}{2}\,\hat{\beta}_9(\log F)^2 + \frac{1}{2}\,\hat{\beta}_{10}(\log L)^2$$

$$+\hat{\beta}_{11} \log M \log S + \hat{\beta}_{12} \log M \log K + \hat{\beta}_{13} \log M \log F + \hat{\beta}_{14} \log M \log L$$

$$+\hat{\beta}_{15} \log S \log K + \hat{\beta}_{16} \log S \log F + \hat{\beta}_{17} \log S \log L$$

$$+\hat{\beta}_{18} \log K \log F + \hat{\beta}_{19} \log K \log L + \hat{\beta}_{20} \log F \log L + \hat{\beta}_{24} TT$$

$$\log G = \hat{\gamma}_0 + \hat{\gamma}_1 \log B + \hat{\gamma}_2 \log M + \frac{1}{2}\,\hat{\gamma}_3(\log B)^2 + \frac{1}{2}\,\hat{\gamma}_4(\log M)^2 + \hat{\gamma}_5 \log B \log M$$

$$\frac{P_M M}{P_Y Y + P_G G} = \hat{\beta}_1 + \hat{\beta}_6 \log M + \hat{\beta}_{11} \log S + \hat{\beta}_{12} \log K + \hat{\beta}_{13} \log F + \hat{\beta}_{14} \log L$$

$$\hat{\gamma}_2 + \hat{\gamma}_4 \log M + \hat{\gamma}_5 \log B$$

$$\frac{P_S S}{P_Y Y} = \hat{\beta}_2 + \hat{\beta}_7 \log S + \hat{\beta}_{11} \log M + \hat{\beta}_{15} \log K + \hat{\beta}_{16} \log F + \hat{\beta}_{17} \log L$$

$$\frac{P_K K}{P_Y Y} = \hat{\beta}_3 + \hat{\beta}_8 \log K + \hat{\beta}_{12} \log M + \hat{\beta}_{15} \log S + \hat{\beta}_{18} \log F + \hat{\beta}_{19} \log L$$

$$\frac{P_F F}{P_Y Y} = \hat{\beta}_4 + \hat{\beta}_9 \log F + \hat{\beta}_{13} \log M + \hat{\beta}_{16} \log S + \hat{\beta}_{18} \log K + \hat{\beta}_{20} \log L$$

$$\frac{P_B B}{P_G G} = \hat{\gamma}_1 + \hat{\gamma}_3 \log B + \hat{\gamma}_5 \log M$$

$$P_C \frac{\hat{b}_2(C - (\hat{a}_{10} + \hat{a}_{11} Hnum))}{(1 - \hat{b}_2)(Z - (\hat{a}_{20} + \hat{a}_{21} Hnum)} = \frac{P_Y Y}{L}(\hat{\beta}_5 + \hat{\beta}_{10} \log L + \hat{\beta}_{17} \log S + \hat{\beta}_{19} \log K + \hat{\beta}_{20} \log F)$$

$$P_c C = (P_Y Y - P_M M - P_S S - P_K K - P_F F) - (P_G G - P_B B)$$

$$T = L + Z$$

The main interest of the analysis is how the optimal value of M, L, Y move as P_G changes. This study considers 4 different price shown in Table 7.

Acknowledgment

The authors would like to thank Fumikazu Yoshida, Masahito Fukami, Masahiko Fujii and Nobuko Yabe for their instructive comments. Any errors in this paper are solely the author's responsibility.

References

[1] Agency for Natural Resources and Energy, Japan. http://www.enecho.meti.go.jp/kaitori/ cited 10th July 2010. (2010) (in Japanese)

[2] Egaitsu N. Nougyoukeizagaku. Second edition. Iwanami. (2002) (in Japanese)

[3] Hokkaido Government. Hokkaido Rakuno Chikusan Kankeishiryo. (2004) (in Japanese)

[4] Ishikawa S., Hoshiba S., Ishida T., Hinata T., Hishinuma T., Hagawa T., Tateyama T., Takeuchi Y., Morita S. Evaluation of Centralized Biogas Plant in dairy from Economic Point of View. *Japanese Journal of Farm Management*. **43**(1). p194-199. (2005) (in Japanese)

[5] Iwamoto H., Yamamot Y., Demomra K. The impact of Applying Envioronmal Conservation Technologies and Environmental Regulations on Dairy Farms:The case of East Hokkaido. *Journal of Rural Economics* Special Issue. p241 — 244. (1999) (in Japanese)

[6] Japan Association of Dairy Helper Organizations. Atarashii Rakuno gijutsu no Kiso to Jissai: kisohen. Japan Livestock Industry Association. (2002) (in Japanese)

[7] Kurosaki T. Kaihatsu no Mikurokeizaigaku. Iwanami. (2002) (in Japanese)

[8] Matsuda J. Hokkaido Agriculture and Biomass Energy. Yoshida. F., Ikeda. M (eds) Sustainable Low-Carbon Society. chapter 9. Hokkaido University Press. (2009)

[9] Ministry of Agriculture, Forestry and Fishery, Japan. Price Indices of Commodities in Rural Areas. Norintokeikyokai. (2009) (in Japanese)

[10] Ministry of Agriculture, Forestry and Fishery, Japan. Production Cost of Farm and Livestock Products. Norintokeikyokai. (1997-2010) (in Japanese)

[11] Ministry of Internal Affairs and Communications, Japan. Annual Report for Consumer Price Index. Japan Statistical Association. (2009) (in Japanese)

[12] Nogyo Doboku Shinbunsha. Hokkaido no Biogas Plant. (2003) (in Japanese)

[13] Ono M, Ugawa H, Evaluation about dairy farming used the concentrative model of biogas-system in Hokkaido. *Japanese Journal of Farm Management*. **43**. p182-187. (2005)(in Japanese)

[14] Toki A., Syuto H., Siheno R. Scale Economy and Technological Progress in Dairy Farming in Hokkaido: Translog Cost Function Approach. *Journal of Rural Economics* Special Issue. p113-120. (2008) (in Japanese)

[15] Sadoulet E., De janvry A. Quantitative Development Policy Analysis. The Johns Hopkins University Press. (1995)

[16] Sonoda T., Maruyama S. Effect of the Internal Wage on output Supply :A Structural Estimation for Japanese Rice Farmers. *American Journal of Agricultural Economics* . **81**. p131-143. (1999)

[17] Umetsu K., Hasegawa S., Kikuchi S., Takeushi Y. Economical and Technological Analysis of Biogas System. *Japanese Journal of Farm Management*. **43**(1). p188-193. (2005) (in Japanese)

Table 1: Data

Variables	Contents	Source
Y	Annual amount of produced milk (t)	PCFLP
M	The number of dairy cows (head)	PCFLP
S	Annual amount of feedstuffs	$P_S S$ P_S
K	Bulding for fairy production	Divideing $P_K K$ by P_K
F	Other input	Dividing $P_F F$ by P_F
L	Annual dairy labor time (hours)	PCFLP
G	Annual amount of generated biogas (m^3)	NDS
B	Cubic capacity of biogas fermenter(m^3)	NDS
$P_Y Y$	Annual household revenue from dairy farming (¥)	PCFLP
$P_M M$	Annual expenditure for dairy cows (¥)	PCFLP
$P_S S$	Annual expenditure for feedstuffs and fertilizer (¥)	PCFLP
$P_K K$	Annual expenditure for buildingfor fairy production (¥)	PCFLP
$P_F F$	Annual expenditure for other expenditure (¥)	PCFLP
$P_B B$	Annual expenditure for biogas fermenter (¥)	NDS
P_Y	Price of Y (¥)	Dividing $P_Y Y$ by Y
P_M	Price of M (¥)	Dividing $P_M M$ by P_M
P_S	Price of S	PICRA (ratio, baseline = 2005)
P_K	Price of K	PICRA (ratio, baseline = 2005)
P_F	Price of F	PICRA (ratio, baseline = 2005)
$SD1$	Management scale dummy less than 20 dairy cows	PCFLP
$SD2$	Management scale dummy from 20 to 50 dairy cows	PCFLP
$SD3$	Management scale dummy from 50 to 80 dairy cows	PCFLP
$SD4$	Management scale dummy more than 80 dairy cows	PCFLP
C	Annual consumption level of household	Dividing $P_C C$ by P_C
$P_C C$	Annual Profit from dairy farming	PCFLP
P_C	Consumer Price Index in Hokkaido region	ARCPI (ratio, baseline = 2005)
Z	Annual leisure time	Subtracting L from 365 days $\times$ 16 hours
Lnum	The number of household member engaged in dairy farming	PCFLP
Hnum	The number of household member	PCFLP

Table 2: Descriptive Statistics of the Data

Variables	Mean	Std.dev
Y	401534.4827	325063.9445
M	46.82625	35.28625
S	11203952.816	8797027.542
K	2246568.734	2126410.23
F	1438247.11	1152012.599
L	4839.29793	1900.84165
p_Y	75.88675	2.6767
p_M	74315.8625	12846.15465
p_S	0.98134	0.077025
p_K	0.98779	0.035174
p_F	0.9894	0.024914
$SD1^*$	28.75%	
$SD2^*$	32.5%	
$SD3^*$	16.25%	
$SD4^*$	22.50%	
TT	2001.075	3.75778
C	9122628.478	6994547.378
Z	10280.46201	1172.20302
Lnum	2.589	0.36797
Hnum	5.035	0.80836
p_C	1.00806	0.0087531
w^*	10657.89007	7989.66868
N	80	

*) Dummy Variable

Table 3: Descriptive Statistics of Biogas Plant

Variables	Mean	Std.Dev
G	85817.11538	69204.01259
B	300.84615	234.53068
M	151.61538	88.67312
P_B	28215.72604	24243.31183
N	13	

Table 4: Estimation Results for Dairy Production Function

Parameters	Estimates	Std.Err	t-value	p-value
β_0	50.4294	16.5669	3.04398	[.002]
β_1	0.00520111	0.339186	0.015334	[.988]
β_2	1.08504	0.371905	2.91751	[.004]
β_3	-0.182932	0.113304	-1.61453	[.106]
β_4	0.065018	0.124065	0.524068	[.600]
β_5	-11.2152	3.29299	-3.40578	[.001]
β_6	0.00548829	0.027954	0.196336	[.844]
β_7	-0.142644	0.042166	-3.38292	[.001]
β_8	0.02832	0.00726986	3.89557	[.000]
β_9	0.011805	0.00781755	1.51002	[.131]
β_{10}	1.64702	0.444624	3.70429	[.000]
β_{11}	0.035655	0.029579	1.20542	[.228]
β_{12}	-0.017648	0.00857925	-2.05702	[.040]
β_{13}	0.00356251	0.00994675	0.358158	[.720]
β_{14}	-0.032085	0.023613	-1.35877	[.174]
β_{15}	0.045279	0.014143	3.2016	[.001]
β_{16}	0.036023	0.01386	2.59904	[.009]
β_{17}	0.034296	0.040072	0.855844	[.392]
β_{18}	-0.028433	0.00646248	-4.39969	[.000]
β_{19}	-0.049179	0.020378	-2.4134	[.016]
β_{20}	-0.042983	0.018712	-2.29713	[.022]
β_{21}	0.795205	0.337477	2.35632	[.018]
β_{22}	0.474292	0.203104	2.33521	[.020]
β_{23}	0.271984	0.107858	2.52168	[.012]
β_{24}	-0.00527613	0.00315021	-1.67485	[.094]
N	80			

Table 5: Estimation Results of the Parameters for Utility Function

Parameter	Estimates	Std.Err	t-value	p-value
a_{10}	37534800	43895500	0.855094	[.392]
a_{11}	-10175200	9470570	-1.0744	[.283]
a_{20}	11056.2	3863.44	2.86175	[.004]
a_{21}	-1156.11	1208.24	-0.956852	[.339]
b_2	0.397564	0.21102	1.88401	[.060]
N	80			

Table 6: Estimation Results of Biogas Production Function

Parameter	Estimates	Std.Err	t-value	p-value
γ_0	-4.5836	3.57221	-1.28313	[.240]
γ_1	1.88179	0.966066	1.94789	[.092]
γ_2	2.85574	1.53554	1.85976	[.105]
γ_3	-0.031139	0.143889	-0.216408	[.835]
γ_4	-0.210806	0.390964	-0.539195	[.606]
γ_5	-0.205554	0.136525	-1.50561	[.176]
N	13			

Table 7: Power Selling Price

Price(¥/ kwh)	P_G^*(¥/ kwh)	
4.5	7.434	Ongoing electricity prices in accordance with the RPS low
14.5	25.159	Electricity prices for dairy farms in Hokkaido
23.7	41.123	Electricity prices for general household in Hokkaido
48	83.287	Electricity prices for solar energy in accordance with the RPS low

*) P_G is calculated based on average methane density in baiogas(58.79%) and average power energy conversion efficiency(29.41%)

Sites for Biomass Plants in Taiwan

Edgardo Reyes Calderon[*], Wen-Chi Huang[**]

* Graduate student, Department of Tropical Agriculture and International Cooperation,
National Pingtung University of Science and Technology (NPUST), Pingtung, Taiwan, ROC.
Tel. (886)-8-7703-202 ext. 6430; Cell. (886)-9-3666-6324; Email: P9722004@mail.npust.edu.tw

**Associate Professor, Department of Agribusiness Management
Joint Appointment with Department of Tropical Agriculture and International Cooperation National Pingtung University of Science and Technology (NPUST), Pingtung, Taiwan, ROC.
Tel. (886)-8-7703202 ext. 7824; Fax (886)-8-774-0190; Email: wenchi@mail.npust.edu.tw

Abstract

Many changes have occurred in Taiwan's economy since it entered the World Trade Organization (WTO) in 2001. Import and export quotas have obligated the country to adjust to WTO's conditions and mandates. In the agriculture sector, the economy has shifted from local production to import of many food products, especially rice. By 2010, due to these changes, fallow land has increased to 260,000 ha. During the same time, new Taiwanese legislation mandates the usage of biofuels (e.g., biodiesel 1% in all motor fuels in 2008, and ethanol 3% by 2011). These conditions have made scholars suggest an alternative use of idle lands that also meets the bioenergy mandates, might be local production of biomass crops and biofuels for energy purposes. To support that idea, we will use an optimized model to locate the best sites for biofuels and bioenergy production plants in Taiwan. The model will include market prices, optimal land use schemes, current infrastructure, and planting of various crops, while meeting the bioenergy targets. The species selected for biomass and bioenergy production are those suggested in particular by Taiwan's Council of Agriculture (COA) as among the best energy crops (sugarcane, sorghum, sweep potato, groundnut, soybean, leucaena, and miscanthus). In this paper we minimize total system costs and find the proper sites for each crop.

Keywords: bioenergy mandates, optimized model, biomass sites

1. Introduction

Developing bioenergy crops in Taiwan has many benefits, it can revitalize agriculture and prosper the country economy; follow farmlands have been estimated about 200-250 thousands hectare every year (Liu and Lin, 2009). Sweet potato, maize, sugarcane, sweet sorghum had been identified as promising biofuel crops. Together with some major agrowaste products: rice straw, rice husk, corncob, corn stover, and groundnut shell. Other sources considered as bioenergy feedstock are branches and leaves left over after pruning fruit crops, mainly wax-apple, mango, pineapple, guava, and litchi. All these annual and perennial crops generate a vast amount of residues that can serve as input in a bioenergy industry in Taiwan.

Although the sources mentioned above, for bioenergy purpose are usually locally available, also requires extensive infrastructure networks for harvesting, transportation, storage, and processing. The design and management of biomass supply chains should account for the local conditions and constraints, such as the existing infrastructure, geographical features of studied region and the competition among several consumers. The relative low energy density (energy per unit volume) of most biomass feedstock tends to increase the cost, emission and complexity of supply chains (Lam et al., 2010).

Biomass supply chains deal with harvesting, densification, drying, storage, and transportation activities. Primary biomass resources are distributed over the area in a region and often available in remote locations. Building the infrastructure to transfer biomass energy over longer distances would tend to increase its cost. Such a scenario would put biomass at disadvantage in purely economic terms (Krotscheck et al., 2000). On the other hand, biomass offers the potential to reduce the environmental impact of energy supply. For Taiwan, another important factor to be considered is the security of energy supply, which has significant importance. Energy generation from domestic sources helps reducing the dependence on foreign imports of crude oil and natural gas. By generating energy from fallow land and agrowaste, the need to maintain follow land idle, or the elimination of large agriculture residues volume, is eliminated simultaneously with the replacement of the fossil fuel.

This paper examines the necessary bioenergy transportation and distribution infrastructure, specifically the flow of material, to potential biomass and biorefineries plant in Taiwan. We determine the optimal construction and expansion plan for biomass and biofuel process in Taiwan to contribute to its bioenergy mandates.

The Energy Supply and Demand Situation in Taiwan

According to the Bureau of Energy (2009), Taiwan’s energy consumption has grown, in the past two decades, from 46.42 million kiloliters of oil equivalent in 1988 to 117.69 in 2008. The sector that consumes more than 50% of the total energy in 2008, was the industrial sector followed by transportation. Figure 1 shows the energy consumption by sectors in different years since 1988 until 2008.

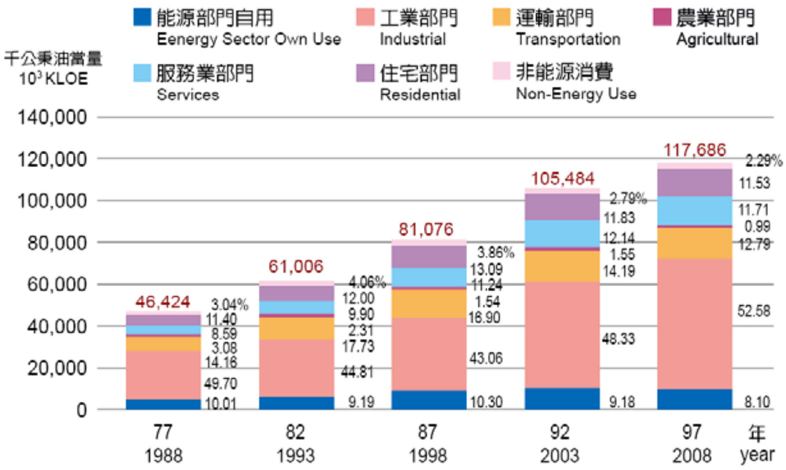


Figure 1. Oil equivalent consumption by sectors in Taiwan (Source: Taiwan's Bureau of energy and Ministry of Economic Affairs, 2009)

Taiwan supply of energy in 1988 was 51.64 million kiloliters of oil equivalent and 142.47 million kiloliters in 2008. Of this total in 2008, locally produced energy contributed 0.66%, and imported energy was 99.34%. Classified by energy form, coal contributed 32.42% in 2008; oil constituted 49.46%; natural gas shared 9.42%; hydropower provided 0.29%; nuclear power provided 8.30%; geothermal, solar and wind power provided 0.04%; and solar thermal 0.08% (Figure 2).

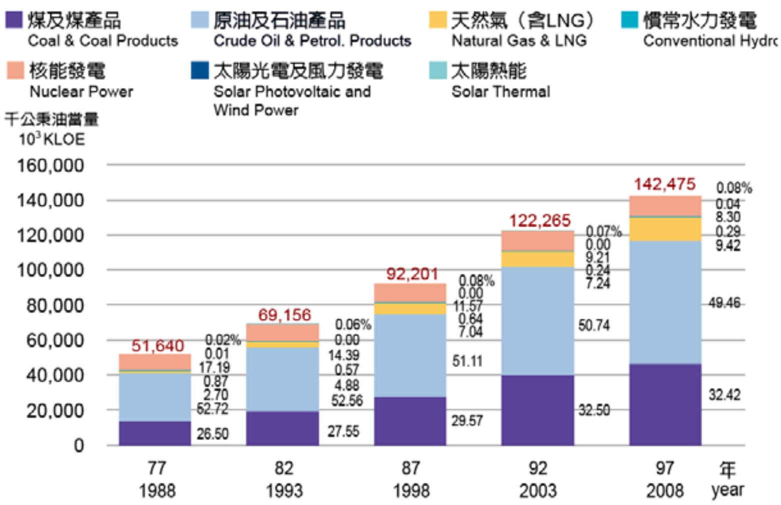


Figure 2. Taiwan’s energy supply and sources (Source: Taiwan's Bureau of energy and Ministry of Economic Affairs, 2009)

Bioenergy and Biofuels in Taiwan

The main reasons Taiwan wants to develop bioenergy policies are the following:

- To improve renewable energy supply, reduce demand for fossil energy, reducing imports of fossil energy.
- To reduce greenhouses gases and air pollutant emission.
- Increasing domestic demand for agricultural products, through maintaining agricultural production and generate agricultural employment.

In order to formulate Taiwan's future energy and industrial development strategy in response to the Kyoto protocol, three National Energy Conferences had been held, in 1999, 2005 and 2009. One of the concrete action plans from those National Energy Conferences is to develop and promote the green (renewable) energy to achieve the goal of about 500 x 10^7 W in terms of installed electricity capacity, or approximately 5% of total energy demand in 2020. With respect to the promotion of biomass energy, there are two development goals set up in 2005 (Tsai, 2008):

- Biofuels goals:

Biofuels	2010	2015	2020
Bioethanol	100-300 x 10^7 L	100 – 300 x 10^7 L	100 – 300 x 10^7 L
Biodiesel	10 x 10^7 L	-	10 x 10^7 L

- Electricity generation from waste-to energy goals:

  Year 2010: 74 x 10^7 W

  Year 2015: 85 x 10^7 W

Year 2020; 103 x 10^7 W (approximately 1.4% of total electricity in terms of installed capacity)

Taiwan's Council of Agriculture identified about 260,000 ha of fallow farmland (double cropped) and 240,000 ha or idle farmland (single cropped) in 2005. Despite these fallow and idle land, in 2008, Taiwan backed off from its plans to develop local biofuel feed stock production in response to historically high grain prices that triggered a global food crisis. Taiwan is now focusing on cellulosic feedstock, which grows better on marginal land and will not compete with food crops on arable land (USDA Foreign Agricultural Service, 2009). Taiwan's Council of Agriculture has identified two main sources of biomass energy: agronomic crops and nonagricultural crops (including agricultural waste). Ethanol crops include sugarcane, sweet sorghum, sweet potato, sugarbeat. For biodiesel, crops included are, soybeans, sunflower, groundnut, rapeseed, peanut, cottonseed. Other ethanol plants were Taiwan is working on is algae. Freshwater algae (*Chlorella pyrenoidosa*), marine species of algae (Neochloris *oleabundans*, *Monalanthus salina*). As well as *Jatropha curcas* and *Recinus communis*.

In July 2008, Taiwan started to implement a one percent biodiesel usage policy that requires all gas stations to supply B1 diesel for motor fuel. Taiwan's demand for B100 to meet the B1 mandate is estimated at 45,000 kiloliters per year, of which approximately one third is likely to be met by imports from the EU. Taiwan uses recycled cooking oil to make B100, and its B100 production capacity is 99,000 kiloliters. Taiwan has tentatively set its goal to implement B2 mandate for motor fuel in 2010 and B5 mandate in 2015.

Eight demonstration E3 gasohol gas stations in Taipei City in 2008 and another five demo gas stations in Kaohsiung City in 2009 are currently providing service. Recently, the Bureau of Energy (MOEABOE) from the Ministry of Economic Affairs, completed a survey on motor vehicles for the types and models of engines to see whether existing motor engines can be fueled using E3 gasohol. The survey results indicated that almost 100% of existing motor vehicles on Taiwan roads can be fueled with E3 gasohol. However, there are some 10 million motorcycles built before in Taiwan whose engines cannot be fueled with E3 gasohol (USDA Foreign Agricultural Service, 2009).

Cost of Biofuels in Taiwan

Producing biodiesel with waste edible oil and imported oil cost NT$24/liter [1] and NT$23/liter, respectively. The cost using cultivated sunflower and soybean reaches NT$75/liter and NT$98/liter, respectively, in 2008 (Huang and Wu, 2008). Considering by-product (oil seed) revenue and profit margins, the price of biodiesel ranges between NT$29/liter and NT$64/liter, which were higher than that of the fossil diesel (NT$26.2/liter, the price on June 09, 2010). Ethanol from sugarcane and sweet potato cost NT$29.70 in 2007, versus NT$29.30 cost of gasoline in June 09, 2010 (USDA Foreign Agricultural Service, 2007).

[1] 1 NT$ is equivalent to 0.0312 US$ on June 24, 2010.

Agrowastes in Taiwan

Agrowastes from plant-based in Taiwan in 2000 were 1.3 million metric tons of rice straw; 3.15 thousand metric tons of rice husk; 73 thousand metric tons of corncob; 178 thousand of corn stover; and 19 thousand metric tons of groundnut shell. Animal wastes in the same year were 7 million metric tons of livestock feces; 11.7 million metric tons of urine; and 6.7 million metric tons of poultry waste (Tsai et al., 2004). Due to the limitation of recent data, and not change in total area harvested in recent years with respect to 2000, these calculations were taken into consideration.

Location of Agrowastes and Bioenergy Crops in Taiwan

The middle and south of Taiwan were found to be the ideal regions to set up bioenergy plants, due to its large plantation area. Sugarcane is suitable for the middle and the south; sweet potato for most of the west; sunflower and soybean are suitable to be cultivated in the south (Taiwan Research Institute, 2006).

Regional Bioenergy Clustering

Our main goal of clustering regions in Taiwan is to aggregate potential main bioenergy crops and agrowaste products. We considered that gathering the biomass flows between the regions will make the logistic more efficient and lower the transportation cost. Also, reduce the environmental impact of all the process. Figure 3 shows that cereals are mainly produced in the middle and south of Taiwan, especially the counties of Changhua, Chiayi, Tainan and Pingtung. Therefore, we clustered the main bioenergy industry and infrastructure in those areas.

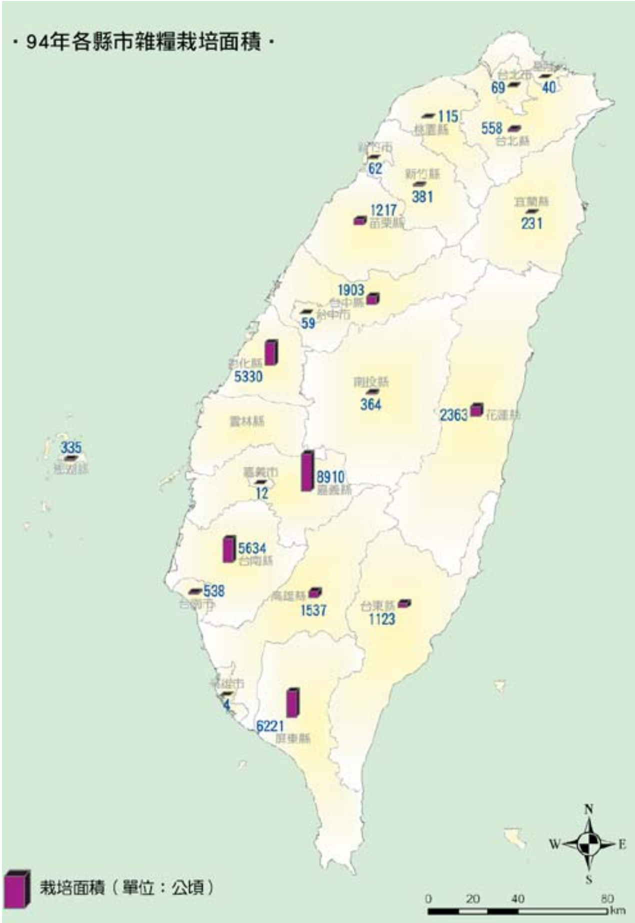


Figure 3. Hectares cultivated of cereals per counties in Taiwan (Source: Council of Agriculture and Service, 2006).

Major orchard plantations are located in the central and south of Taiwan: Taichung, Nantou, Chiayi, Tainan, Kaohsiung and Pingtung counties (Figure 4.) Taiwan high intensive fruit management produces agrowaste, annually, especially branches and leaves left after harvesting and pruning. Not data is available of how much that agrowaste represents.

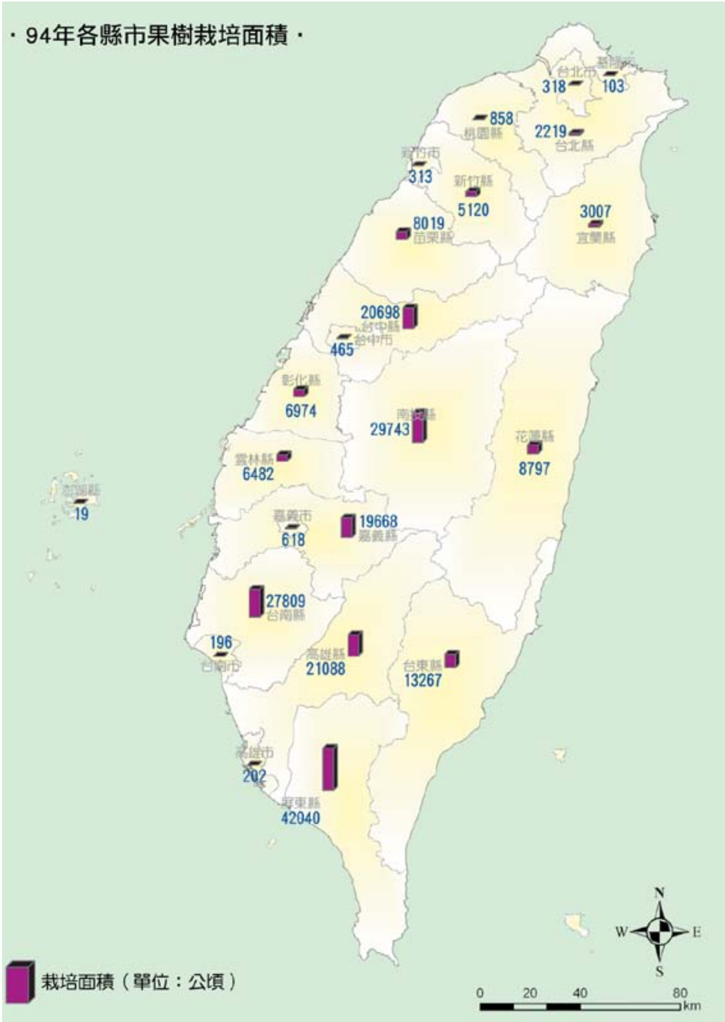


Figure 4. Areas and counties of cultivation of fruits trees in Taiwan (Source: Council of Agriculture and Service, 2006).

Accordingly, to the distribution of Taiwan's population, the major bioenergy demand locations are in the cities located in the same west region of the country. In this case, the north has the highest population density and the greatest number of households (Figure 5), representing this areas the major bioenergy demand location. Nevertheless, there are three main cities in the south, close to the main production of agrowaste and potential bioenergy crops, i.e., Kaohsiung, Pingtung, and Tainan.

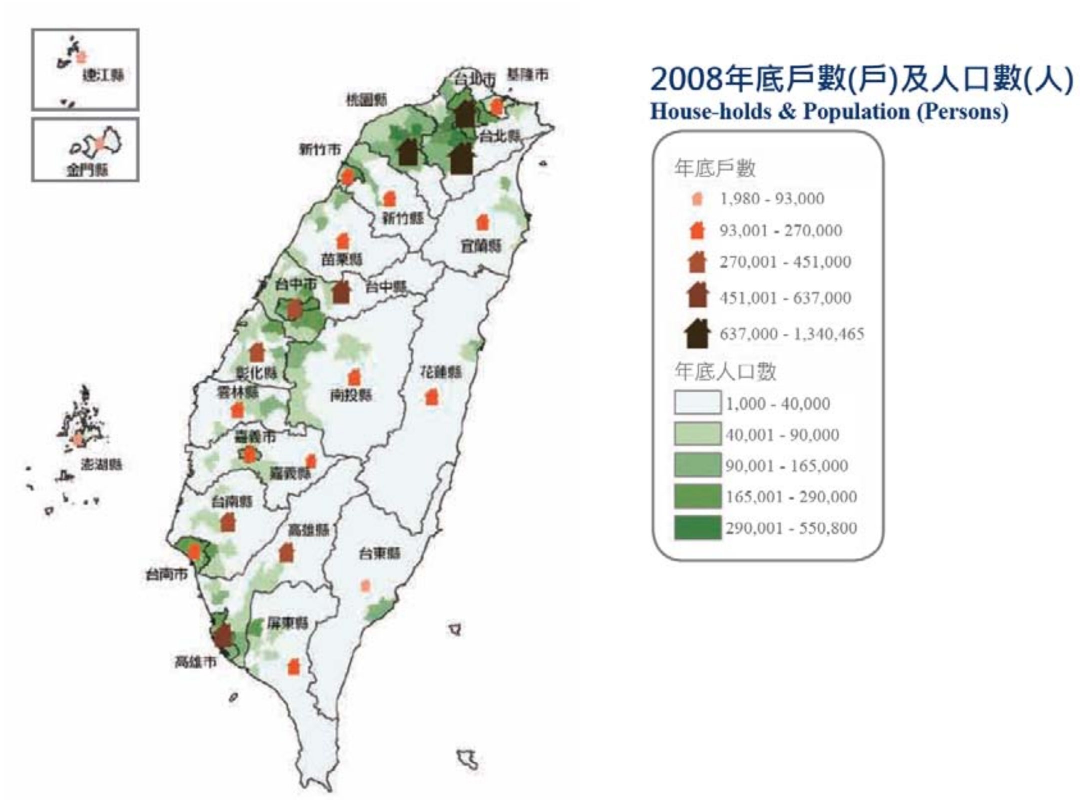


Figure 5. Location of household and population in Taiwan (Source: Urban and Housing Development Department, 2009)

Energy Distribution Infrastructure in Taiwan

The main energy and fuel distribution infrastructure in Taiwan reflects the close relationship between population, households and energy grid distribution (Figure 6). Due to the lack of indigenous energy (energy locally generate), and the highly dependence of import energy sources, most of the major power generation plants (e.g., refineries, nuclear stations, etc.) are near the sea, where the main ports are located. Connecting bioenergy plants would be accessible due to the widely distribution grid throughout the country.

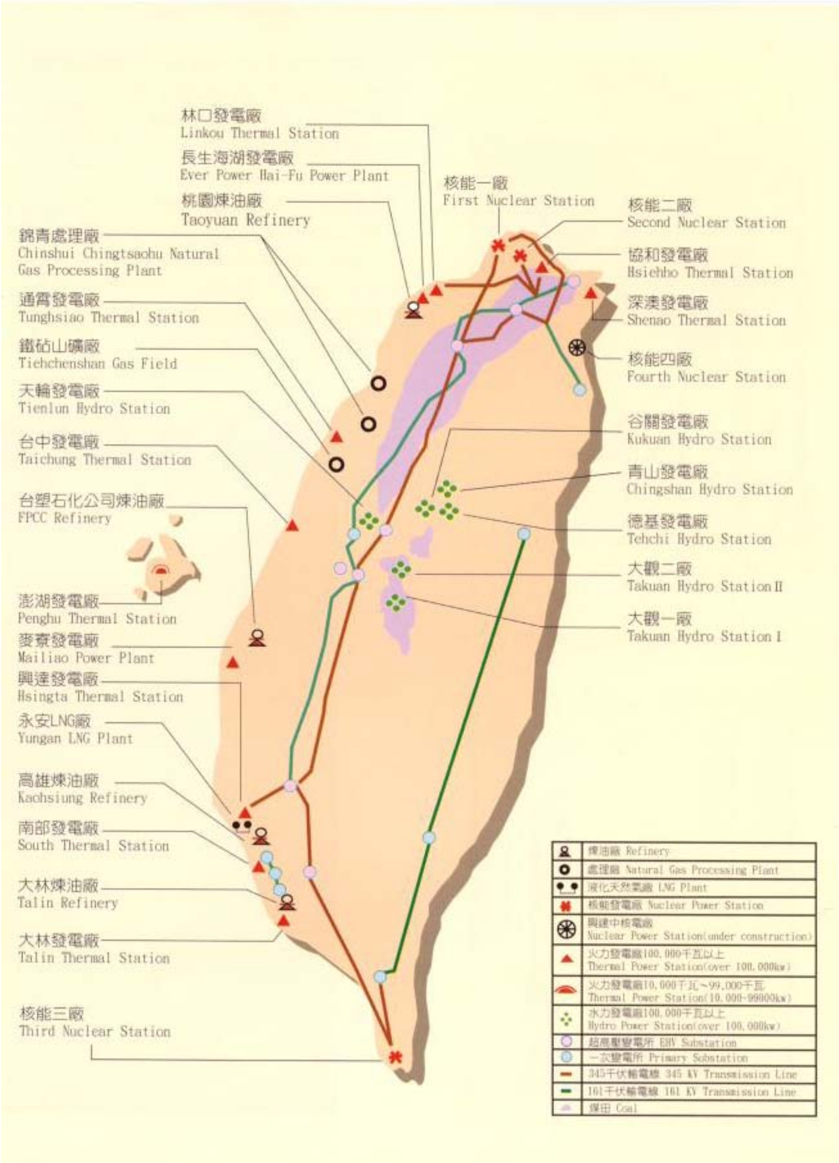


Figure 4. Energy supply system in Taiwan (Source: Bureau of Energy and Ministry of Economic Affairs, 2009)

2. The Model Description

A large-scale mixed-integer programming model has been used o determined the optimal land use for feedstock production and collection in Taiwan.

Transportation and distribution are important factors in the biofuel supply chain. To support decision-making on infrastructure design, an analytical modeling tools is used to simulate the optimal supply chain.

To study the economic feasibility of different sources of bioenergy, economists have used mathematical programming models. The idea is to locate the processing facilities so as to minimize the total transportation cost. The facility-location problem has been solve using integer programming and select biorefinery locations from a set of candidates, considering pre-specified criteria such as water availability or distance to the transportation network. A mathematical programming model by (Kaylen et al., 2000) analyzed economic feasibility of producing ethanol from lignocelllulosic feedstocks at minimal cost, distinguishing between capital cost, operation cost, feedstock cost, and transportation cost. As plant capacity increases, marginal operating cost declines due to economies of scale. However, the transportation cost increase because feedstock will have to be shipped from longer distances.

Based on transportation costs from production sources of the feedstock by the road/railroad network, certain locations in Taiwan may be more suitable for bioenergy crops. The model aims to minimize the total system costs for transportation and processing of feedstock, transportation of ethanol from refineries to blending terminal, cost of shipping ethanol from blending terminal to demand destination, capital investment in refineries, and transportation of the co-products to livestock producing areas.

The central and south of Taiwan is used as a test in this case study because, as mentioned before, is the country's largest agriculture production area of agrowastes and potential bioenergy crops. All the counties in these regions are considered as a potential supply area (where agrowastes can be collected or bioenergy crops can be produced) and a demand destination to which biofuels or bioenergy can be delivered. In addition, each county is assumed a candidate plant location where a biofuel production or cellulosic biorefinery, or both, can be built in any given year. Cellulosic biorefineries are assumed to process both crops residues and energy crops. Production and distribution stages of the biofuel supply chain involve several integrated decision layers that must be addressed simultaneously (Khanna et al., 2010), these include: (1) the type of processing facilities, their capacities, years in which they are built, and locations; (2) the amount of raw materials transported from production regions to biorefineries; (3) the amount of biofuel deliveries to existing blending facilities (terminal and from here to demand destinations; and (4) by-products shipments from refineries to livestock production regions.

The model we develop here is adapted from the mixed-integer programming model developed by Kang et al. (2010) for the state of Illinois, U.S., presented in the *Handbook of Bioenergy Economics and Policy*.

Model results

Complete model results will be presented at the conference. Including:

- Projected regional production of bioenergy crops
- Availability of main agrowaste throughout the year
- Biomass plant location (Biorefineries)
- Optimal future biomass supply chain sizes
- Total number of biomass plants to establish to process annual production of agrowaste and energy crops.

3. References

Bureau of Energy, Ministry of Economic Affairs, 2009. Energy statistical annual reports. MOEA, Taipei.

Bureau of energy, Ministry of Economic Affairs, 2009. Energy Statistics Handbook 2008. Bureau of Energy, MOEA, Taipei, pp. 26-29, 58-66.

Council of Agriculture, Service, F., 2006. Taiwan's natural resources and ecological database III: Agriculture, forestry, animal husbandry and fisheries. in: N.T.U.B.R. Center (Ed.). Forest Service, Taipei, pp. 215.

Huang, Y.-S., Wu, J.-H., 2008. Analysis of biodiesel promotion in Taiwan. *Renewable & Sustainable Energy Reviews*, 12, 1176 - 1186.

Kang, S., Onal, H., Ouyang, Y., Scheffrang, J., Tursun, U.D., 2010. Optimizing the biofuels infrastructure: Transportation networks and biorefinery locations in Illinois. in: Natural Resources Management and Policy (Ed.). Springer, New York, pp. 151-173.

Kaylen, M., Dyne, D.L.V., Choi, Y.-S., Blase, M., 2000. Economic feasibility of producing ethanol from lignocellulosic feedstocks. *Bioresource Technology*, 19-32.

Khanna, M., Scheffran, J., Zilman, D., 2010. Hanbook of Bioenergy Economics and Policy, New York.

Krotscheck, C., Konig, F., Obernberger, I., 2000. Ecological assessment of integreted bioenergy systems using the sustainable process index. *Biomass & Bioenergy*, 18, 341-368.

Lam, H.L., Peter Sabev Verbanow, Klemes, J.J., 2010. Optimisation of regional energy supply chains utilising renewables: P-graph approach. *Computers and Chemical Engineering*.

Liu, S.-Y., Lin, C.-Y., 2009. Development and perspective of promising energy plants for bioethanol production in Taiwan. *Renewable Energy*, 34, 1902-2907.

Taiwan Research Institute, 2006. The assessment of external economic benefit in developing energy crops. in: Institute of Agriculture Engineering Research Center (Ed.), Taipei.

Tsai, W.-T., Chou, Y.H., Chang, Y.M., 2004. Progress in energy utilization from agrowastes in Taiwan. *Renewable & Sustainable Energy Reviews*, 8, 461-481.

Urban and Housing Development Department, 2009. Urban and Regional Development Statistics: Republic of China (Taiwan) 2009. in: C.f.E.P.a. Development (Ed.). Executive Yuan, R.O.C. (Taiwan), Taipei, pp. 165.

USDA Foreign Agricultural Service, 2007. Taiwan Bio-fuels Annual. in: G.A.I. Network (Ed.). USDA, pp. 4.

USDA Foreign Agricultural Service, 2009. Biofuels Annual: Taiwan Mandates One Percent Biodiesel. in: G.A.I. Network (Ed.). USDA.

Environmental and Economic Evaluations of Biogas Plants in Hokkaido from Life Cycle Assessment (LCA)

Hokkaido University
Faculty of Environmental Earth Science
Nobuko Yabe

1. Introduction

The introduction of biogas plant (BGP) with anaerobic digestion can be regarded as a promising measure to reduce greenhouse gas (GHG) in Hokkaido. Hokkaido has about 836,000 cows and this is about half of the total cows in Japan. Scale of a daily farming in Hokkaido is large compared to the other regions and also a large concentration of daily farmers is found. Hence, Hokkaido is the appropriate place for installing BGPs. In reality, however, BGPs are not adopted actively in Hokkaido.

Many researchers investigated the introduction of BGPs and found advantages and disadvantages when a BGP was introduced in a particular area. However, the entire results when BGPs are introduced in Hokkaido are not understood. In addition, since the previous researches used various assumptions and scope of researches, it is needed to organize the results of previous literatures and provide the entire results of the introduction of BGPs in Hokkaido.

The aim of this research was to capture the entire picture on the introduction of centralized BGPs in Hokkaido in terms of environmental and economic impacts. GHG emissions from conventional compost treatments and those from BGP systems were examined. Total cost for BGP constructions and energy production from BGPs were estimated. Furthermore, price of renewable electricity produced in BGPs and cost of GHG emission reduction were estimated to present benchmark for cost-effectiveness.

2. Methods and Assumptions

2.1 Amount of manure and number of daily farmers

To obtain number of cow and daily farmer in Hokkaido in 2007, Census of Agriculture and Forestry 2005 (Ministry of Agriculture, Forestry and Fisheries, 2005) and Statistical Survey on Livestock (Ministry of Agriculture, Forestry and Fisheries, 2007) are used.

Cow is classified into two: cow 2 years old and over and cow under 2 years old. Cows 2 years old and over are composed of milking cow, dry cow and virgin heifer. Cow under 2 years old are composed of virgin heifer and breeding cow. Share of each cow type of 2 years old and over is estimated based on the data of Statistical Survey on Livestock as follows: milking cow 78%, dry cow 13 % and virgin heifer 9%. Share of each cow type of under 2 years old is estimated based on research by Hoshiba et al. (Hoshiba et al., 2006) as follows: virgin heifer 15% and breeding cow 85%.

Amount of manure, nitrogen and organic matter in manure are calculated based on the data of table 1.

Table 1. General manure production

	Milking cow	Dry cow	Virgin heifer	Breeding cow
Feces (kg/day)	45.5	29.7	29.7	17.9
Urine (kg/day)	13.4	6.1	6.1	6.7
Nitrogen in feces (g/day)	152.8	38.5	38.5	85.3
Nitrogen in urine (g/day)	152.7	57.8	57.8	73.3
Organic matter in feces (%)			16	
Organic matter in urine (%)			0.5	

Data source: Hoshiba et al. (2006)

2.2 Composting treatment

Conventional compost treatments emit GHG in three stages. The data for the estimation of GHG emissions from compost treatment are shown in table 2. First stage is manure fermentation. In this stage, methane (CH_4) and nitrous oxide (N_2O) are emitted from faces, urine and slurry. Second stage is taking out and disseminating compost and liquid manure to farm field. In this stage, vehicles and machines are used to take out and disseminate compost and liquid manure and light oil is consumed. Carbon oxide (CO_2), CH_4 and N_2O from light oil are estimated. The final stage is volatilization. After disseminating compost, farm field emits N_2O. The extent of emission quantity depends on type of farm field.

Single-seeding pasture (grass pasture) emits more N_2O than mixed-seeding pasture (gramineae and leguminous).

Table 2. Data for estimation of GHG emissions from compost treatment

Manure fermentation	CH_4 (%)	N_2O (%)	
Feces	2.59	4.5	
Urine	0.92	0.75	
Slurry	0.92	0.75	
Dissemination	CO_2 (kg/t)	CH_4 (kg/t)	N_2O (kg/t)
Compost	2.37	2.36×10^{-5}	4.00×10^{-5}
Liquid manure	0.37	0.37×10^{-5}	0.62×10^{-5}
Volatilization	Single-seeding pasture	Mixed-seeding pasture	
N_2O from compost (%)	0.05	0.038	
N_2O from liquid manure (%)	0.05	0.038	

Data source: Hoshiba et al. (2006)

2.3 Introduction of BGPs

Required number of BGP for all daily farmers in Hokkaido are estimated assuming one BGP is installed per 100 ㎢ (5.6 km radius) of land area of each municipality. For example, if city A's land area is 350 ㎢, four BGPs assumed to be installed. The reason for this assumption is the result of study by Ito and Nakata (Ito and Nakata, 2008). They examined the optimal allocation of centralized BGPs in Kuzumaki town in Iwate prefecture. According to their study, transport cost of manure per electricity generated could be minimized when average radius between a daily farmer and a BGP is 5-8 km. Although this number is site-specific, this study regards it as useful information.

The basic data of a centralized BGP are shown by table 3. This setting is based on the actual data from the centralized BGP in Betsukai and the BGP at the Rakuno Gakuen University. Since the rate of biogas production fluctuates according to various conditions, two cases of 20㎥/t and 30㎥/t are estimated in this study.

Table 3. Setting condition on the centralized BGP

Items	Setting	Remark
Temperature of digester	35	Mesophilic digestion
Rate of biogas production	20 ㎥/t,　30 ㎥/t	Per 1t raw slurry
Methane concentration	60%	
Calorific value of methane	36MJ/㎥	

2.4 Total cost of BGPs

Total cost of BGP constructions are estimated based on the results of study by Umetsu et al. (Umetsu et al., 2005). Their study indicated the relation between scale of BGP and construction cost and operating cost of BGP based on the information from 21 firms as follows.

Relation of scale of BGP and construction cost: $y=4997.7x^{0.6261}$, $R^2=0.9973$.

Relation of scale of BGP and operating cost: $y=270.79x^{0.5459}$, $R^2=0.9951$.

By using these functions, cost of each BGP is estimated and then it is counted as on a regional basis. Useful life of a BGP is assumed to be 15 years.

2.5 Energy production in BGPs

Energy generated at BGP is calculated by amount of manure (slurry) and basic data of a centralized BGP shown by table 3. Two different rates of biogas production (i.e., 20㎥/t and 30㎥/t) are used to obtain total energy generated.

Each BGP is assumed to use combined heat and power production facility (CHP) to obtain energy from methane gas. In this study, all heat and a portion of electricity generated are utilized for the operation of the BGP. The amount of electricity consumed at the BGP is estimated by the function presented by Umetsu et al. (Umetsu et al., 2005).

Relation of scale of BGP and electric requirement: $y=48.047x^{0.722}$, $R^2=1$.

Power generation efficiency and heat efficiency are assumed to be 25% and 50%, respectively.

2.6 CO_2 emission by the introduction of BGPs

CO_2 emission due to the introduction of BGPs are composed of CO_2 emission due to the constructions of BGP and CO_2 emission from the energy generated in BGPs. CO_2 emission due to the constructions of BGP are estimated based on the data of the study by Hoshiba et al. (Hoshiba et al., 2006). They estimated CO_2 emission when a farm scale BGP is constructed based on the construction data of a farm scale BGP at Hokkaido Prefectural Konsen Agricultural Experiment Station. Table 4 presents the detailed data of CO_2 emission from the construction of a farm scale BGP. Since the data of CO_2 emission when a centralized BGP is constructed are unavailable, the estimation of this study utilizes the data of table 4.

Table 4. CO_2 emission when a farm scale BGP (3 ㎥/day) is constructed

	CO_2 emission (t/ years)
Production process of construction material	7.53
Transport process of construction materials	3.26
Construction	0.2
Dismantlement	1.06
Total	12.05

Data source: Hoshiba et al. (2006)

3. Results

3.1 Total cost of introducing BGPs

Table 5 shows that the estimation results of cost of introducing BGPs in 14 subprefecture in Hokkaido. Initial investment is about 365.1 billion yen if BGPs are installed for all daily farmers. Tokachi, Abashiri, Nemuro and Kushiro account for about 66% of the total initial investment. Since BGPs are assumed to be operated for 15 years, construction cost per year is calculated by dividing initial investment by 15. Total construction cost per year is about 24.3 billion yen. Operating cost which includes labor costs, water bill payment and supplies expenses is about 14.2 billion yen. Total cost per year is ranged from 0.4 up to 8.7 billion yen.

Table 5. Total Cost of Introduction BGPs

(Million yen)

Subprefecture	Initial Investment	Construction Cost per year	Operating Cost per year	Total Cost per year
Ishikari	8,903	594	361	954
Oshima	11,368	758	478	1,236
Hiyama	4,149	277	179	456
Shiribeshi	5,962	397	267	665
Sorachi	7,030	469	321	789
Kamikawa	25,651	1,710	1,102	2,812
Rumoi	12,949	863	517	1,381
Soya	28,069	1,871	1,084	2,955
Abashiri	59,294	3,953	2,364	6,317
Iburi	7,564	504	328	832
Hidaka	10,588	706	464	1,170
Tokachi	83,521	5,568	3,182	8,750
Kushiro	48,325	3,222	1,827	5,049
Nemuro	51,753	3,450	1,807	5,257
Total	365,126	24,342	14,281	38,622

Note: Useful life of a BGP is assumed to be 15 years.

3.2 Energy production from BGPs

Energy generated in BGPs is shown in table 6. Available power energy is the power energy when all methane gas is used for electric power generation. Since a portion of power energy is used for operation of BGP, surplus power energy is obtained after extracting power energy consumed at BGPs from available power energy. When rate of biogas production is 30m^3/t, twice surplus power energy can be obtained and sold compared to that in the case of the rate of biogas production of 20m^3/t. Total available heat is assumed to be used for the operation of BGPs.

Table 6. Energy production from BGPs

Subprefecture	Available power energy (MWd)		Power energy consumed at BGPs (MWd)	Surplus power energy (MWd)		Total Available Heat (TJ)	
	A	B		A	B	A	B
Ishikari	325	488	185	141	303	5,623	8,435
Oshima	360	541	227	134	314	6,228	9,342
Hiyama	110	165	80	31	86	1,906	2,859
Shiribeshi	137	206	110	28	96	2,376	3,563
Sorachi	150	224	127	23	98	2,585	3,878
Kamikawa	713	1,069	497	216	572	12,317	18,475
Rumoi	522	783	274	247	508	9,015	13,522
Soya	1,258	1,887	616	642	1,271	21,742	32,613
Abashiri	2,351	3,526	1,256	1,095	2,270	40,619	60,928
Iburi	202	444	145	57	299	3,495	5,243
Hidaka	270	406	200	70	205	4,674	7,011
Tokachi	4,100	6,150	1,868	2,232	4,282	70,849	106,274
Kushiro	2,445	3,667	1,090	1,354	2,576	42,241	63,362
Nemuro	3,763	5,645	1,284	2,479	4,361	65,027	97,540
Total	16,707	25,201	7,959	8,748	17,242	288,697	433,045

Note: A and B shows the case of rate of biogas production of 20 ㎥/t, and 30 ㎥/t, respectively.
Power generation efficiency is 25%, heat efficiency is 50%.

3.3 GHG reduction by introducing BGPs

Table 7 shows the potential GHG reduction by installing BGPs in Hokkaido. A reduction of GHG emissions ranged from 125 up to 135 Mt of carbon dioxide equivalents per year.

If rate of biogas production is 20㎥/t, GHG emissions due to construction of BGPs is larger than the GHG emission reduction of surplus electricity. In this case, total GHG emissions could be negative by considering GHG emission reduction of compost treatment.

Table 7. GHG emissions due to introduction of BGPs (t-CO_2eq.)

Subprefecture	(1) Construction of BGPs per year	(2) Surplus electricity	Subtotal (1)+(2)	(3) Compost treatment	Total (1)+(2)+(3)
Case of rate of biogas production of 20 ㎥/t					
Ishikari	2,867	−1,744	1,123	−24,526	−23,403
Oshima	3,176	−1,658	1,517	−28,661	−27,143
Hiyama	972	−381	591	−8,708	−8,117
Shiribeshi	1,211	−343	869	−11,559	−10,690
Sorachi	1,318	−283	1,035	−15,285	−14,250
Kamikawa	6,280	−2,680	3,600	−60,670	−57,070
Rumoi	4,596	−3,068	1,529	−47,294	−45,765
Soya	11,086	−7,969	3,117	−106,466	−103,349
Abashiri	20,711	−13,583	7,128	−191,294	−184,166
Iburi	1,782	−712	1,071	−20,935	−19,865
Hidaka	2,383	−871	1,513	−11,886	−10,373
Tokachi	36,125	−27,690	8,436	−310,278	−301,842
Kushiro	21,538	−16,802	4,737	−177,811	−173,074
Nemuro	33,157	−30,764	2,392	−268,904	−266,512
Total	147,205	−108,547	38,657	−1,284,277	−1,245,620
Case of rate of biogas production of 30 ㎥/t					
Ishikari	2,867	−3,763	−896	−24,526	−25,422
Oshima	3,176	−3,894	−719	−28,661	−29,379
Hiyama	972	−1,066	−94	−8,708	−8,801
Shiribeshi	1,211	−1,195	16	−11,559	−11,543
Sorachi	1,318	−1,211	107	−15,285	−15,178
Kamikawa	6,280	−7,102	−822	−60,670	−61,492
Rumoi	4,596	−6,304	−1,708	−47,294	−49,001
Soya	11,086	−15,775	−4,689	−106,466	−111,155
Abashiri	20,711	−28,166	−7,455	−191,294	−198,749
Iburi	1,782	−1,967	−184	−20,935	−21,120
Hidaka	2,383	−2,549	−165	−11,886	−12,051
Tokachi	36,125	−53,127	−17,001	−310,278	−327,279
Kushiro	21,538	−31,967	−10,429	−177,811	−188,240
Nemuro	33,157	−54,111	−20,954	−268,904	−289,858
Total	147,205	−212,197	−64,993	−1,284,277	−1,349,270

3.4 Price of renewable electricity and CO_2

Table 8 and 9 present price of renewable electricity generated in BGPs and cost of GHG emission reduction by introducing BGPs. The price of renewable electricity is calculated from cost of BGPs introduction and surplus power energy. The lowest price is 50 yen per kWh of Nemuro and the highest price is 1,443 yen per kWh of Sorachi. If electricity generated in BGPs can be sold the price in table 8, the cost of BGP construction could be profitable.

The cost of GHG emissions reduction shown in table 9 is estimated from cost of BGPs introduction and total GHG emission reduction. Nemuro needs 18,136 yen to reduce 1 ton of GHG emissions, while Hidaka has to pay up to 112,798 yen per 1 ton of GHG emission reduction. The difference between two area is about 6 times.

Table 8. Price of renewable electricity

(yen/kWh)

Subprefecture	Price of surplus electricity	
	A	B
Ishikari	283	131
Oshima	385	164
Hiyama	618	221
Shiribeshi	1,003	287
Sorachi	1,443	337
Kamikawa	542	205
Rumoi	233	113
Soya	192	97
Abashiri	240	116
Iburi	604	116
Hidaka	695	237
Tokachi	163	85
Kushiro	155	82
Nemuro	88	50

Note: A and B shows the case of rate of biogas production of 20 m^3/t, and 30 m^3/t, respectively.

Table 9. Cost of GHG emission reduction

(yen/t-CO_2eq.)

Subprefecture	Cost of GHG emission reduction A	Cost of GHG emission reduction B
Ishikari	40,782	37,544
Oshima	45,520	42,056
Hiyama	56,173	51,805
Shiribeshi	62,179	57,584
Sorachi	55,391	52,003
Kamikawa	49,268	45,725
Rumoi	30,165	28,173
Soya	28,596	26,588
Abashiri	34,301	31,784
Iburi	41,889	39,400
Hidaka	112,798	97,091
Tokachi	28,989	26,736
Kushiro	29,170	26,820
Nemuro	19,725	18,136

Note: A and B shows the case of rate of biogas production of 20 m^3/t, and 30 m^3/t, respectively.

4. Conclusion

In conclusions, it has been clarified in this study that introduction of centralized BGPs is effective for reducing GHG emissions. By installing BGPs for all daily farmers, from 125 up to 135 Mt of carbon dioxide equivalents per year could be reduced. This accounts for 1.9 % of GHG emissions in Hokkaido in 2007. To reduce this amount of GHG emissions, 38.6 billion yen is required per year. However, if renewable electricity can be sold at around 100 yen per kWh, BGPs in dailyland such as Nemuro, Kushiro, Tokachi and Soya could be profitable.

Reference

Hoshiba, et al. 2006. “Application of LCA methodology to local policies: Case studies on biogas plants in Betsukai-Chou, Hokkaido,” NEDO Report.

Ito, Y. and Nakata, Y. 2008. “Allocation and Introduction of Biomass Plants Considering Geographic Distribution of Livestock Manure,” *Journal of the Japan Institute of Energy,* 87: 56-67.

Ministry of Agriculture, Forestry and Fisheries. 2005. *Census of Agriculture and Forestry 2005.*

Ministry of Agriculture, Forestry and Fisheries. 2005. *Statistical Survey on Livestock.*

Umetsu, et al. 2005. “Economical and Technological Analysis of Biogas System,” *Nougyou Keiei Kenkyu,* 43 (1): 188-193.

Contribution of China's Non-fossil Energy Development in Power Generation to Carbon Intensity Reduction

Hancheng Dai[a,*], Toshihiko Masui[b]

[a]dai.h.aa@m.titech.ac.jp, Department of Social Engineering, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550, Japan

[*] Corresponding author. Tel.: +81-29-850-2355; fax: +81-29-850-2422

[b]masui@nies.go.jp, National Institute for Environmental Studies Social & Environmental Systems Division, 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506 Japan

Abstract

China has made commitment in Copenhagen to reduce its carbon intensity by 40% to 45% compared with 2005 level by 2020, and is determined to vigorously develop sustainable energies. This study analyzes the effects of China's non-fossil energy development target that could help to achieve China's Copenhagen commitments. A hybrid static CGE model that includes technology details in electricity sector is developed. The results show that carbon intensity will fall by 6.2% if China's targets of the non-fossil energy development plan could be achieved in 2020, and it will fall by 8.5% as a result of annual energy efficiency improvement of 2%. However, the rest of the 40-45% target must be realized by other measures such as carbon tax. It is also found that although coal remains the main energy source, yet its share in primary energy will fall to 52-55%. On the other hand, the share of non-fossil energy will rise to 15-17% in 2020.

1 Introduction

Shortly prior to 2009 United Nations Climate Change Conference in Copenhagen, China announced an ambitious goal to reduce its economy's carbon intensity by 40-45% from 2005 level by 2020, together with comprehensive climate policy packages that may help to achieve this goal. Among these policy packages, developing non-fossil energies, especially in power generation, is one of the most important counter measures.

Early in 2007, National Development and Reform Committee (NDRC) released "China's Medium and Long Term Plan for Renewable Energy". The plan set specific targets for developing the capacity of hydropower, wind power, biomass energy, solar energy and other non-fossil energies. In 2010, many of 2007's targets have been achieved ahead of the planned time table. Therefore, China is now considering updating to more ambitious targets for developing non-fossil energies.

With a hybrid static CGE model that includes technology details in electricity sector, this study aims to evaluate how much China's carbon intensity could be reduced if the latest non-fossil energy targets in power generation are achieved in 2020. In addition, electric power technology dynamics in different scenarios are also investigated.

2 Methodology

The methodology is hybrid static AIM/CGE (Asian-pacific Integrated Model/Computable General Equilibrium) model developed by National Institute for Environmental Studies (NIES), Japan. The AIM/CGE model is solved by MPSGE/GAMS (Rutherford, 1999).

2.1 Production

There are 41 sectors in this model (see in Table 1), including 7 energy sectors. Activity level of each sector follows a nested constant elasticity of substitution (CES) function as shown in Fig 1 to Fig 3. Inputs are categorized into intermediate commodities, energy commodities, and primary factors of labor and capital.

Table 1: Sector Definition in This Model

Nr	Sector	Nr	Sector
1	Mineral mining	21	Animal Husbandry (livestock)
2	Textiles and wearing	22	Other agriculture
3	Chemicals	23	Water production and supply
4	Nonmetallic mineral products	24	Construction
5	Other nonmetallic products	25	Scientific research and education
6	Iron and steel smelting and pressing	26	Health, social security and welfare
7	Nonferrous metal	27	Services
8	Grain mill products	28	Railway transport
9	Vegetable oil refining	29	Road transport
10	Slaughtering and meat processing	30	Urban public transport service of passengers
11	Drink and beverage	31	Water transport
12	Other food manufacturing	32	Air transport
13	Paper and paper products	33	Other transport
14	Metal products	34	Storage and warehousing
15	Transport equipment	35	Coal mining
16	Machinery	36	Extraction of petroleum
17	Electronic equipment	37	natural gas
18	Other manufacturing	38	Petroleum and nuclear fuel processing
19	Agriculture	39	Coking

20	Forestry	40	Gas production and supply
		41	Electricity

For energy conversion sectors of oil refinery, town gas and coke (Fig 1), crude oil and coal are considered as material inputs, which are not substitutable with other inputs. Activity output is determined by a fixed coefficient aggregation of non-energy intermediate commodities, energy intermediate commodities, and primary factors. The primary factors composite is a CES aggregation of labor and capital with a Cobb-Douglas form, and capital is substitutable with the composite of energy inputs, which is a CES aggregation of electricity and fossil fuels with elasticity of substitution of 0.1, and fossil fuels are further disaggregated into five types with elasticity of substitution of 0.5. The composite of non-energy inputs is in Leontief form.

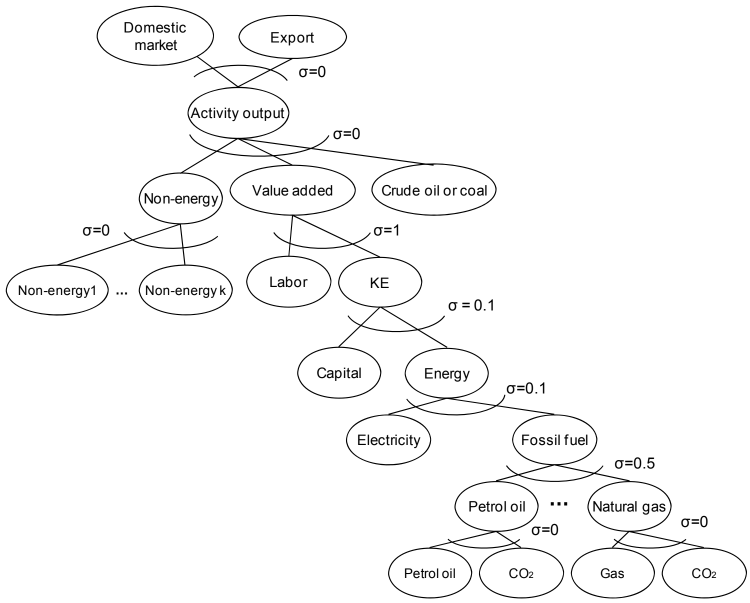


Fig 1: Nesting of Production Structure for Energy Conversion Sectors

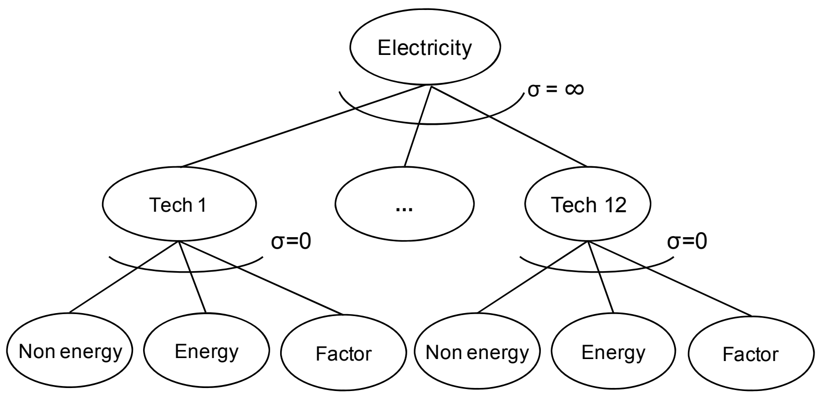


Fig 2: Nesting of Production Structure Electricity Sector

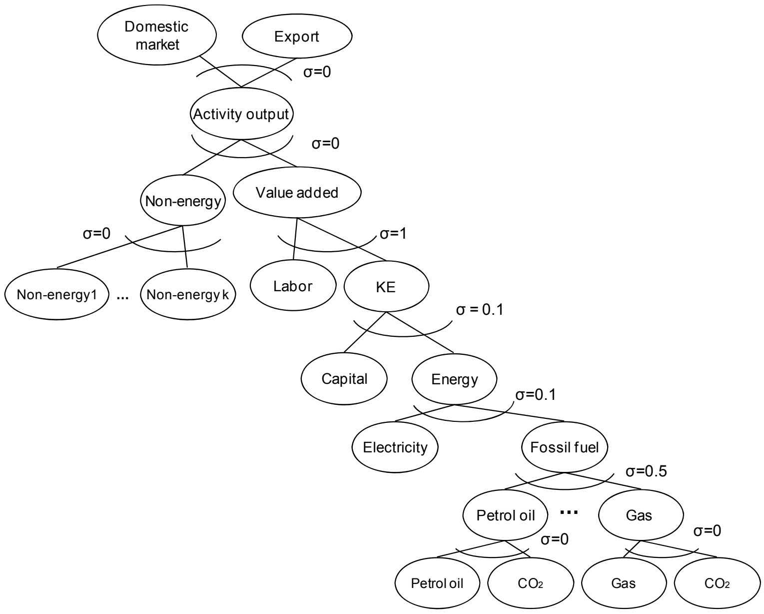


Fig 3: Nesting of Production Structure for Other Sectors

For electricity sector (see Fig 2), electricity is generated by 12 technologies listed in Table 2. Each technology consumes either fossil fuels or non-fossil energies and is perfectly substitutable with each other. Production function of each technology is the same as energy conversion sectors as showed in Fig 1. Disaggregation of electricity sector into 12 technologies follows the methodology developed by Sue Wing (2006; Sue Wing, 2008).

For other sectors, nested CES function is shown in Fig 3, the only difference from Fig 1 is that energy is not treated as material input anymore; instead, composite of energy inputs is substitutable with capital with elasticity of substitution of 0.1.

Table 2: Technologies for Electricity Generation in China

Fuel	Technology	2005 (GW)	2020 (GW)
Coal	Subcritical Steam Turbine		
Coal	Supercritical Steam Turbine		
Coal	Ultra-Supercritical Steam Turbine		
Coal	Circulating Fluidized Bed		
Coal	Integrated Gasification Combined Cycle		
Oil	Oil		
Natural gas	Gas		
Non-fossil	Hydro	116	300
Non-fossil	Nuclear	7	80
Non-fossil	Wind	1.26	150
Non-fossil	Biomass	2	30
Non-fossil	Solar	0.07	2

2.2 Household

Household and government are final consumers. The representative household receives income from the rental of primary factors, and maximizes utility by choosing the levels of consumption of commodities, subject to the constraints of its income and commodity prices. It is assumed that both labor and capital are fully employed, perfectly competitive, and perfectly mobile among all sectors except for electricity sector. In electricity sector, labor is mobile while capital is immobile. We also assume that the representative household has Cobb-Douglas preferences as shown in Fig 4.

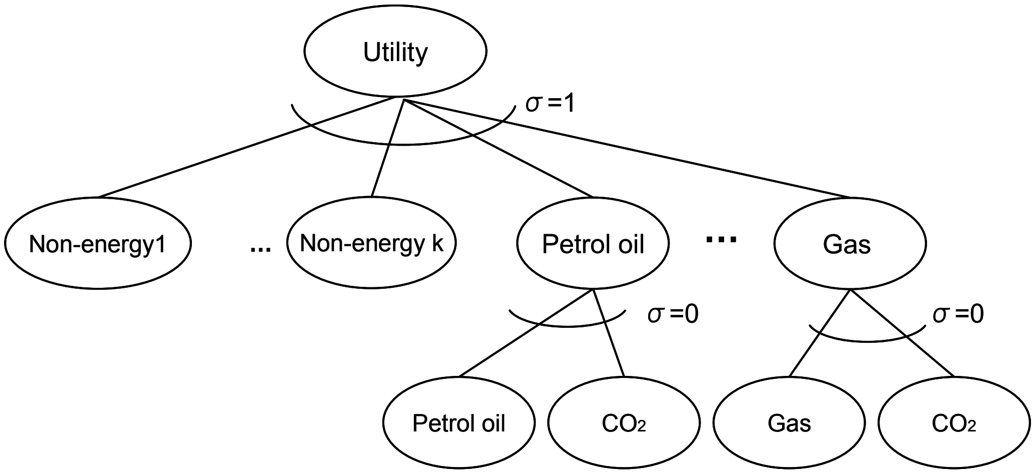


Fig 4: Nesting of Consumption Structure

2.3 Government

The role of government is to collect taxes, including carbon tax, and disburse these revenues to firms and households as subsidies and lump-sum transfers. The government purchases goods and services to maximize a Cobb-Douglas utility function.

2.4 Investment

Investment is treated as another final demand and is assumed to increase linearly at the same pace as GDP growth rate.

2.5 International trade

This model is an open economy model and follows the small open economy assumption, meaning that an economy is small enough that its policies do not alter the world prices, interest rates or incomes. Produced goods are distributed to domestic and international markets. Armington assumption is used to distinguish identical domestic goods and imported goods, assuming that the elasticity of substitution between imported and domestic goods is 4. Net trade surplus in 2020 is assumed to be fixed as the level of 2005; accordingly, currency exchange rate is determined endogenously.

2.6 CO_2 abatement

CO_2 emissions come from combustion of fossil fuels. If CO_2 emission constraints are imposed to industries sectors and household, carbon tax will be induced and collected by the government. Carbon abatement is essentially achieved through three types of substitution(Okagawa, 2010). Firstly, inter-fuel substitution, as marginal abatement cost raises energy costs, agents will substitute CO_2-intensive fuels like coal with less CO_2-intensive fuels like natural gas or non-fossil energies. Secondly, inter-factor substitution, for sectors except for energy conversion sectors, agents will substitute energy-composite goods with capital. Thirdly, inter-goods substitution, as the relative prices of CO_2-intensive goods rise, the relative demand for these goods will become lower. In this way, the economy will be decoupled from carbon.

3 Base year data

The dataset used in this model include input-output table, energy balance table, CO_2 emission factors of fossil fuels, and data on characteristics of electricity generation technologies. All the datasets are converted to the base year of 2005.

3.1 Energy balance table in 2005

Generally speaking, CGE model treats energy consumption in monetary terms. However, we need the information of energy consumption in physical terms. In order to turn the monetary energy consumption in input-output table into physical terms, data from energy balance table (EBT) are used (National Bureau of Statistics of China (NBS), 2006). Through dividing monetary value in SAM by energy consumption in EBT of each corresponding energy type, we can get the average prices of all energy types in the base year, and these prices are further used to calculate energy consumption in all sectors. Another purpose of using EBT is to check the consistency between SAM and EBT. It is found that total energy consumption is consistent since the calculated average prices are in accordance with the real price in 2005, but energy consumption in sectors are not consistent between the two sources, this may be caused by different statistical methodology when the two datasets are made. Therefore, we only used the total energy consumption for each energy type.

3.2 CO2 emission factors

CO_2 emissions are calculated according to the method recommended by IPCC (Ministry of Science and Technology Economy and Energy, 2001) by multiplying the demands for various fossil fuels with their corresponding potential carbon emission factor and fraction of oxidized carbon.

3.3 Data for characteristics of electricity generation technologies

The bulk of CO_2 abatement induced by carbon taxes comes from electricity generation sector. Therefore, it turns out necessary to build up a hybrid CGE model that incorporates electricity technology details and provides insight into technology dynamics in electricity sector. The key step is to disaggregate the electricity sector in social accounting matrix into input-output data of different technologies that represent each technology's engineering characteristics. Sue Wing (2006; Sue Wing, 2008) developed a transparent and replicable methodology to disaggregate electricity sector. Following this methodology, we developed an element model to disaggregate China's electricity sector into 12 major technologies. The data needed (see in Table 3) include electricity generation by technologies (Mao, 2007), generation cost and efficiency of technologies (International Energy Agency, 2008), fossil fuel prices in the base year, and input share of each technology. In addition, data of China's non-fossil energy use in 2005 and non-fossil energy development target in 2020 in electricity sector are also collected(NDRC, 2007).

Table 3: Data of electricity technologies in base year

Technology	Generation cost (yuan/kWh)	Generation share (%)	Efficiency (%)
Subcritical Steam Turbine	0.21	55.45%	35.4%
Supercritical Steam Turbine	0.23	7.70%	43.5%
Ultra-Supercritical Steam Turbine	0.30	1.87%	47.0%
Circulating Fluidized Bed	0.30	1.87%	47.0%
Integrated Gasification Combined Cycle	0.32	0.10%	50.0%
Oil	0.54	5.565%	35.4%
Natural gas	0.47	0.886%	35.4%
Hydro	0.38	23.416%	-
Nuclear	0.32	2.642%	-
Wind	0.34	0.082%	-
Biomass	0.59	0.361%	-
Solar	3.40	0.0742%	-

4 Scenario

This study analyzes four scenarios, including Reference Scenario, CM-Tech, CM40 and CM45 (Table 4). Few assumptions are set for reference scenario, CM-Tech scenario means that non-fossil energy technologies will be employed, and scenarios of CM40 and CM45 mean carbon intensity in terms of GDP will be reduced by 40% and 45% in 2020 compared to 2005, respectively.

The following assumptions on driving forces of economy are identical for all scenarios: annual energy efficiency improvement is 2%, annual total factor productivity improvement is 1% for agriculture, 2% for service sector and 3% for industry(Zheng, 2007; Vennemo, Aunan et al., 2009), population will increase annually by 0.3% between 2005 and 2020(Chen, 2006), annual labor productivity improvement is 5%, and capital in 2020 will increase by 2.8 folds compared to 2005. These assumptions allow annual average GDP growth rate to be around 8% over the period 2006-2020.

Table 4: Parameters for Four Scenarios

Parameter	Scenario			
	RS	CM-Tech	CM40	CM45
Carbon intensity reduction from 2005	None	None	40%	45%
Non-fossil energy	Unchanged from 2005	Increase as development target (Table 2)		
Energy efficiency	Annual improvement of 2%			
Technology Improvement	Agriculture: annual increase of 1% Industry: annual increase of 3% Service: annual increase of 2%			
Capital change	2.8 times of increase from 2005			
Population	Annual increase of 0.3% between 2005 and 2020			
Labor productivity	Annual increase of 5% per year from 2005			

The scenarios differ from each other in the assumption of non-fossil energy uses and carbon constraints. In the reference scenario, capital input of non-fossil energy technologies will be at the same level of 2005 without any additional investment, and there will be no carbon constraints. In the scenario of CM-Tech, China's non-fossil energy target in 2020 will be achieved (see in Table 2), and this is transformed in the model by assuming that capital change is equal to capacity change of each technology. In the scenarios of CM40 and CM45, aside from employment of non-fossil technology in electricity sector, carbon constraints are set exogenously to ensure that China's carbon intensity by GDP in 2020 will be reduced by 40% and 45% compared to 2005, respectively.

The purpose of scenario setting in this way is to single out each policy type, namely energy efficiency improvement, non-fossil energy development, and carbon constraints, to examine their effects one by one. The results are showed in the next section.

5 Results

This section demonstrates the results of this simulation in terms of GDP, carbon dioxide emission, electricity generation by technologies and total primary consumption in all scenarios.

5.1GDP and Carbon Dioxide Emission

Table 5: GDP, CO_2 Emission, Carbon Intensity and Carbon Price in All Scenarios

Scenario	CO_2 Emission (Bil.ton)	Carbon Intensity (Ton-CO_2/10k yuan)	GDP (Billion yuan)	Carbon intensity reduction from 2005	Carbon price (yuan/ton-CO_2)
Base	5.21	2.82	18500		
RS	15.26	2.58	59206	8.5%	
CM-TECH	14.11	2.39	59142	15.3%	
CM40	9.93	1.69	58771	40.0%	329.67
CM45	9.06	1.55	58462	45.0%	450.99

Table 5 shows GDP, carbon emission and intensity in all scenarios. GDP is mainly driven by investment, labor increase and technology improvement, in this model annual GDP growth between 2005 and 2020 is 8.0% to 8.1%.

Carbon emission in 2005 is 5.21 billion tons. In reference scenario, CO_2 emissions in 2020 are almost three times in 2005. In CM-TECH, almost one billion tons of CO_2 emissions are reduced due to non-fossil energy development. In CM40 and CM45, CO_2 emissions are reduced to 9.93 and 9.06 billion tons, respectively.

Carbon intensity in the reference scenario falls to 2.58 tons CO_2 per ten thousand yuan as a result of energy efficiency improvement of 2% per year, which is equal to a reduction of 8.5% from 2005 level. In the CM-TECH scenario, if China's non-fossil energy development target could be realized, a further reduction of 6.8% would be achieved. In the scenarios of CM40 and CM45, due to introduction of carbon constraints, carbon intensity will be as low as 1.69 and 1.55 tons CO_2 per ten thousand yuan, corresponding to 40 % and 45% reduction from 2005.

Carbon prices in reference scenario and CM-TECH are zero since no carbon constraints are imposed in these two scenarios. In CM40 and CM45, however, constraints on carbon emission will induce carbon prices to be 329.7 and 451.0 yuan per ton CO_2, respectively.

5.2 Electricity generation by technologies

Table 6 shows technology dynamics in electricity generation sector. The first five technologies use coal as fuel, including Subcritical Steam Turbine (SubST), Supercritical Steam Turbine (SupST), Ultra-Supercritical Steam Turbine (SSupST), Circulating Fluidized Bed (FBC), and Integrated Gasification Combined Cycle (IGCC). The sixth use oil and seventh use natural gas as fuel. The last five technologies consume non-fossil fuels. In the model we assume that more investment will be installed in the counterfactual scenarios than in reference scenarios to develop advanced IGCC technologies and non-fossil technologies, while less investment in subcritical steam turbine. Investment in other technologies such as SupST, USupST, FBC, oil and natural gas remains unchanged from 2005 level.

Table 6: Technology Dynamics in Electricity Generation Sector (bil. kwh)

Technology	Base	RS	CM-TECH	CM40	CM45
SubST	1671.08	8070.80	6132.86	4058.38	3287.75
SupST	216.51	735.91	746.85	645.90	654.37
SSupST	39.37	89.69	90.92	86.79	89.94
FBC	39.37	134.53	136.38	130.18	134.91
IGCC	1.97	4.49	6.82	6.64	6.91
Oil	66.04	68.27	71.25	103.23	118.31
Gas	12.06	31.63	32.02	34.63	36.60
Hydro	395.20	491.30	989.71	1122.90	1177.64
Nuclear	53.09	69.34	557.83	614.84	637.80
Wind	1.53	2.01	201.68	221.82	229.91
Biomass	3.90	5.08	61.25	67.68	70.27
Solar	0.14	0.20	4.96	5.23	5.33
Total	2500.3	9703.3	9032.5	7098.2	6449.7

SubST: Subcritical Steam Turbine; SupST: Supercritical Steam Turbine; SSupST: Ultra-Supercritical Steam Turbine; FBC: Circulating Fluidized Bed; IGCC: Integrated Gasification Combined Cycle.

The results show that total electricity consumption will rise from 2500 billion kilo watt hour in 2005 to 7098.2 and 6449.7 billion kilo watt hour in CM40 and CM45, respectively, and some trends can be noticed for technologies that utilize coal, oil, natural gas and non-fossil fuels. Electricity generated from subcritical steam turbine decreases dramatically in counterfactual scenarios, while generation from other fossil fuel technologies remains relatively steady or even increases slightly. As a whole, however, the share of fossil-fuel fired electricity will fall from 81.8% in 2005 to 71.4 % and 67.1% in CM40 and CM45, respectively.

Table 7: Increase of Power Generation from Non-fossil Energy (2020/2005)

	Plan	CM-TECH	CM40	CM45
Hydro	2.6	2.5	2.8	3.0
Nuclear	11.4	10.5	11.5	12.0
Wind	119.0	131.8	144.9	150.2
Biomass	15.0	15.7	17.3	18.0
Solar	28.6	35.4	37.3	38.1

On the other hand, non-fossil electricity enjoys steady increase. According to the development plan, non-fossil energy in 2020 would increase by 2.6, 11.4, 119, 15 and 28.6 times of those in 2005 for hydro, nuclear, wind, biomass and solar energy (see Table 7), respectively. In the CM-TECH scenario, China's non-fossil energy target in 2020 is realized, and non-fossil electricity accounts for 18%, this share continues to rise up to 28% and 33% in the CM40 and CM45 scenarios, respectively.

5.3Primary Energy Consumption

Table 8: Primary Energy Consumption

Energy	Base	RS	CM-TECH	CM40	CM45
Coal	1548.28	4569.08	4136.16	2634.36	2331.10
Oil	466.33	1339.11	1334.23	1283.61	1258.31
Gas	62.19	210.24	209.34	156.60	147.09
Hydro	138.96	172.75	348.00	394.83	414.08
Nuclear	18.67	24.38	196.14	216.19	224.26
Wind	0.54	0.71	70.91	77.99	80.84
Biomass	1.37	1.78	21.54	23.80	24.71
Solar	0.05	0.07	1.74	1.84	1.88
Total	**2236.39**	**6318.11**	**6318.07**	**4789.22**	**4482.26**

*primary electricity is converted following the way that generation of 1 kwh electricity consumes 0.352 kg coal equivalent.

Primary energy consumption is shown in Table 8. It indicates that total primary energy consumption increases from 2.236 billion tons of coal equivalent in 2005 to 6.318, 6.318, 4.789 and 4.782 billion tons of coal equivalents in the reference, CM-TECH, CM40 and CM45 scenarios, respectively. Compared with the reference scenario, oil consumption remains rather stable in the counterfactual scenarios, while consumption of coal and natural gas reduces by 26%-49% in CM40 and CM45. Coal remains to be China's major primary energy, yet its share drops from 69% in 2005 to 66%, 55% and 52% in the latter three scenarios. Share of natural gas consumption remains at the level of 3.3% in all counterfactual scenarios. By contrast, share of oil climbs from 21% in 2005 to 26.8% in CM40 and 28.1% in CM45, which indicates that fuel switch from coal to oil is occurring.

Non-fossil energies also experience rapid growth. In 2005, non-fossil energy merely accounts for 7.1% of total primary energy consumption. However, it rises to 10.1%, 14.9% and 16.6% in CM-TECH, CM40 and CM45, respectively.

Energy intensity is another important indicator. In the CM40 and CM45 scenarios, energy intensity will reduce by 36.6% and 44.2% from 2005's level, corresponding to annual reduction of 3.0% and 3.8%, respectively.

6 Discussion

This study's estimation of CO_2 emission in 2005 (5.21 billion ton) is within the range of other estimations. For example, Mao (2009) estimates that China's CO_2 emission in 2005 is 5.33 billion tons, while Wang (2009) estimates it to be 5.06 billion tons.

However, compared to other studies, this study's CO_2 emission in reference and counter measure scenarios is higher. For example, the CO_2 emission in reference scenario is merely 8.18 billion tons by Wang (2009) and 9.6 billion tons in World Energy Outlook 2009 (International Energy Agency, 2009), the latter of which are approximately the same as the emissions in CM45 of this study. These differences result from different assumptions embedded in the models. First, GDP growth is assumed to be faster than the above two studies, which would cause CO_2 emission at a higher level. Second, energy efficiency improvement is assumed to be lower than other studies. In fact, the reference scenarios of other studies are more like CM40 or CM45 of this study, in which carbon intensity is already reduced by over 40% in 2020. Third, methodology difference plays a role, IEA (2009) used bottom-up type technology model, which is different from top-down type CGE model in this study.

As for emissions in CM40 and CM45 scenarios, it should be noted that as long as China's GDP continues to grow at the annual rate of around 8% by 2020, which is necessary to guarantee social stability believed by many researchers and policy-makers, and as long as the carbon intensity will reduce by 40% to 45% from

2005 level, the CO_2 emissions in 2020 calculated by this model will be acceptable, although it is still much higher than projection of 450 scenario (which is 8.3 billion tons) in World Energy Outlook 2009.

This model's simulation for non-fossil energy capacity is in accordance with China's goal. In 2009's UN climate change summit held in New York, China's President Hu claimed that China will increase nuclear or non-fossil fuels to 15 percent of primary energy by 2020 (The New York Times, 2009; Xinhua News, 2009). This share is very close to this model's results. As seen in Table 8, in CM40 and CM45, electricity from nuclear and non-fossil fuels accounts for 14.9% and 16.7% of primary energy.

Energy intensity reduction rate calculated by this model is lower than the 1980-2000 experience of China (Vennemo, 2009), and is lower than China's goal for the 2006-2011 period of 4% per year, and is equal to the reference scenario of Wang (2009). This implies that the energy intensity reduction rate by 2020 calculated in this model is feasible from a historical perspective, and consequently, China's carbon intensity commitment is achievable since CO_2 emission is highly related to fossil energy consumption.

7 Conclusion

With a hybrid static CGE model that includes technology details in electricity sector, this study analyzes the effects of China's non-fossil energy development target that could help to achieve China's Copenhagen commitments. Several messages can be concluded from this study:

First, contribution of China's non-fossil energy development in electricity generation to carbon intensity reduction is assessed. The results indicate that China's non-fossil energy targets in 2020 contribute about 6.8% to carbon intensity reduction, or equivalent to almost one billion tons of CO_2 emission reduction. In addition, it is found that energy efficiency improvement is crucial for carbon intensity reduction. In this study, an annual energy efficiency improvement of 2% leads to carbon intensity reduction of 8.5%. However, efforts in improving energy efficiency and developing non-fossil energy are not sufficient to realize the 40% to 45% reduction. Other policy instruments such as carbon tax should be introduced to realize the rest of carbon intensity reduction target.

Second, impacts of China's carbon intensity target on electricity generation and technology employment in electricity sector are significant. Compared to reference scenario, consumption of electricity is 38% and 46% less in CM40 and CM45, respectively. Share of coal-fired power plants reduces from 93% in the reference scenario to 65% in the CM45 scenario. Inefficient subcritical steam turbine technology is replaced by more advanced technologies such as circulating fluidized bed technology. More electricity is generated from oil-fired power plants. Furthermore, non-fossil fuels will replace fossil energies. The share of electricity generated from non-fossil energies will rise from 18% in 2005 to 29% in CM40 and 33% in CM45.

Third, primary energy consumption and energy mix will see huge change. Total primary energy consumption in CM40 and CM45 will be 4.789 and 4.782 billion tons of coal equivalents, respectively, which is equal to a respective reduction of 24% and 29% compared to reference scenario. Although coal remains the main energy source for China, yet its share will reduce from almost 70% in 2005 to 52% in CM45 scenario. Share of natural gas in primary energy will continue to be as low as around 3.3%. It is found that China will be more dependent on oil and non-fossil energy, with oil share rising to 28% and non-fossil energy share rising to 16.6% in CM45 scenario.

8 Reference

Chen, W. (2006). "China Population Prospects: 2005-2050." Population Research **4**: 93-95.

IEA (2009). "World Energy Outlook 2009."

International Energy Agency (2008). World Energy Outlook 2007. Paris, OECD/IEA.

International Energy Agency (2009). World energy outlook 2009. Paris, OECD/IEA.

Mao, R. (2007). A Study of Approaches and Methods to Meet China's 20% Energy Efficiency Target for 2010.

Mao, Y. (2009). Impact of marketization of China's economy on carbon emission and energy supply and demand. 2050 China energy and CO2 emissions report. Study team of 2050 China energy and CO2 emissions report. Beijing, Science Press**:** P164.

Ministry of Science and Technology Economy and Energy. (2001). "Supply of an instrument for estimating the emissions of greenhouse effect gases coupled with the energy matrix." from http://ecen.com/matriz/eee24/coefycin.htm (Economia &Energia); 2010.5.

National Bureau of Statistics of China (NBS) (2006). China Energy Statistical Year Book 2006. Beijing, China Statistics Press.

NDRC (2007). China's Medium and Long Term Plan for Renewable Energy.

Okagawa, A. (2010). Model Structure and Future Tasks. Unpublished discussion script.

Rutherford, T. F. (1999). "Applied General Equilibrium Modeling with MPSGE as a GAMS Subsystem: An Overview of the Modeling Framework and Syntax " Computational Economics **14**(1-2): 1-46.

Sue Wing, I. (2006). "The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technologies and the cost of limiting US CO2 emissions." Energy Policy **34**(18): 3847-3869.

Sue Wing, I. (2008). "The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technology detail in a social accounting framework." Energy Economics **30**(2): 547-573.

The New York Times. (2009). "Proposals Lag Behind Promises on Climate." Retrieved 5.30, 2010, from http://www.nytimes.com/2009/09/23/science/earth/23climate.html.

Vennemo, H., K. Aunan, et al. (2009). "Benefits and costs to China of three different climate treaties." Resource and Energy Economics **31**(3): 139-160.

Vennemo, H., Kristin, A., Henrik, L., Seip, H.M. (2009). "Environmental pollution in China: status and trends." Review of Environmental Economics and Policy.

Wang, K., C. Wang, et al. (2009). "Analysis of the economic impact of different Chinese climate policy options based on a CGE model incorporating endogenous technological change." Energy Policy **37**(8): 2930-2940.

Xinhua News. (2009). "Full-text speech of President Hu at the opening ceremony of UN climate change summit." Retrieved 5.30, 2010, from http://news.xinhuanet.com/world/2009-09/23/content_12098887.htm.

Zheng, Y. (2007). Understanding Total Factor Productivity. Sustainable Economic Increase and Total Factor Productivity. Tsinghua University, Beijing.

Empirical Study of Environmentally Livable Index and Pollution Control Investment for Chinese Cities

YU Fang[1], Peng Fei, Cao Dong, Wang Jinan (Chinese Academy for Environmental Planning, 100012, Beijing, China)

Jianglin (Beijing Academy for Environmental Science, 100037, Beijing, China)

Ian V. Green (Culpin Planning Limited, Bristol, United Kingdom)

Abstract: While the environments of more and more Chinese cities are becoming less polluted following successful introduction of pollution control and environment renovation measures in recent years, more attention is now being given to the livability of cities. However, these successes are often not quantifiable and are not universally recognized. Based on a survey of globally-recognized urban livability indices and their monitoring systems, the paper is to develop and agree with the government counterparts on a verifiable and measurable environmental livability index system targeting the PRC cities, and find a suitable approach for investment assessments in reaching the benchmarks, i.e. the costs of producing changes in environmental livability. With the Chinese Environmental Liveability Index System developed in the paper, environmental performance of 33 Chinese cities were ranked and the environmental challenges of these cities are identified with the further Pressure-State-Response analysis and trend analysis. With a comprehensive analysis with the trends of long-term environmental livability and the pollution control investment of Chinese cities, more effective and aim-oriented incentives and investment policies for urban environmental livability improvement are put forward in this paper.

Key words: Environmentally Livable Index, Analytical Hierarchy Process, Pressure-State -Response Analysis, Investment

1. Introduction

In china, while the environments of more and more cities are becoming less polluted following successful introduction of pollution control and environment renovation measures in recent years, more attention is now being given to the livability of cities. However, these successes are often not quantifiable and are not universally recognized.

Most of the developed countries have established indexing of environmental livability of its cities, a popular tool to rate the respective progress of countries and cities, and to identify the shortcomings. Environmental livability, a crucial element of the quality of life, is a quality of an area as perceived by residents, employees, customers and visitors. Increasing environmental livability is closely linked to efforts to prevent pollution and reduce waste, conserve natural resources and wildlife habitat, protect endangered species, and reduce our ecological “footprint”. Efforts to define, quantify, and monitor urban environmental livability assist in achieving the overall goal of urban sustainability.

The presence of a well defined and comprehensive indexing of urban environmental sustainability, the respective monitoring system, and city ranking for the PRC will be a major contribution towards strengthening the scientific basis for policy making and implementation for environmentally sustainable development through (i) promoting environmental agenda between PRC policy makers, urban managers, and the general public; (ii) understanding present and future gaps; and (iii) creating a scientific methodology of environmental investments and evaluating impacts of long-term environmental investments.

Based on a survey of globally- recognized urban livability indices and their monitoring systems, we exerted to develop and agree with the government counterparts on a verifiable and measurable environmental livability index system targeting the PRC cities, and find a suitable approach for investment assessments in reaching the benchmarks, i.e. the costs of producing changes in environmental livability. With a comprehensive analysis with the trends of long-term environmental livability and the pollution control investment of Chinese cities, more effective and aim-oriented incentives and investment policies for urban environmental livability improvement are put forward in this paper.

[1] Correspond author, yufang@caep.org.cn; Tel 86 10 84915270, Fax 86 10 84915995.

2. International experience

According to the UN, the proportion of people living in urban areas has risen to fifty percent and will continue to grow to two-thirds, or 6 billion people, by 2050. With this in mind, it is essential that urban areas are planned and managed effectively. Developing specific indicator systems for urban areas is becoming increasingly important. There are a number of globally recognized urban environmental indicator initiatives. These include: (i) the United Nations Centre for Human Settlements (UNCHS) Indicators Programme; (ii) the World Bank's (WB) Global Urban Observatory (GUO)[1]; (iii) Agenda 21 initiatives[2]; and (iv) the UNDP indexes[3]. These international indicator initiatives fall into three separate conceptual approaches: (i) the systems approach; (ii) thematic / index approach; and (iii) the policy approach.

A desk-survey has been conducted of globally recognized urban livability indices and their monitoring systems. Analysis of the collected material has included evaluation of their efficacy towards: (i) promotion of environmental agenda between policy makers, urban managers and the general public and understanding present and future gaps; (ii) creating a scientific methodology of environmental investments; (iii) evaluating impacts of long-term environmental investments; and (iv) applicability to the development of PRC indices.

Whilst a number of frameworks have been developed, there has been a general consensus in the international community that different countries should develop their own indicators in order to reflect their individual political and cultural environments[4,5]. The recommended framework for developing the Environmental Livability Index System (ELIS) in PRC is a combination of the systems approach, using the PSR model, and the thematic approach. The combination of the two frameworks allows the concept of livability to be incorporated into the system. Specific elements of what makes up livability can then be defined and identified, such as air quality and livability. The PSR model will then be used to analyze the issues identified.

3. Development of Environmentally Livable Index for Chinese cities

3.1Construction of indicator system

This paper seeks to develop the Environmental Livability Index (ELI), an index for tracking, evaluating and reporting on a city's environmental livability (EL) and its improvement. The index will also provide a support tool for policy analysis and decision making of pollution control investment. The Environmental Livability Index System (ELIS) will be a system consisting of ELI as well as all the indicators and sub-indices for deriving ELI. The ELIS will also integrate impacts of social and economic activities on the environment, as shown in Figure 1.

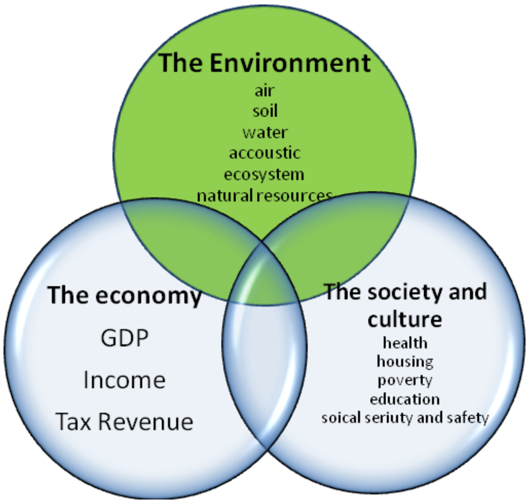


Figure 1. Scope of the Indicators

The ELI system consists of three levels, an aggregated ELI, a sub-index and indicators. Sub-indices are proposed based on the analysis of China's urban environmental issues above. Seven indices for addressing the above major urban issues are included in the urban livability index as water environment, water resource, air environment, solid waste, acoustic environment, ecological environment, domestic liveability and environmental management.

Under each sub-index, indicators are selected according to the PSR model and various criteria for section. The four key criteria – representative, measurability, analytical soundness and data availability- are suggested based on these previous works. Following the above criteria, 8 indicators are selected for water environment, 3 indicators for water resource, 11 indicators for air environment, 6 indicators for solid waste, 1 indicator for acoustic environment, 4 indicators for ecological environment, 4 indicators for domestic livability, and 4 indicators for environmental management. This makes a total of 41 indicators, among which 13 indicators reflecting the environmental state and pollution control efficiency are selected to calculate the Environmental State Index (ESI), and 13 pressure indicators to calculate the Environmental Pressure Index (EPI) and 15 indicators to calculate the Environmental Response Index (ERI). In addition, the Environmental Investment Index (EII) was also calculated. ESI is the weighted mean of atmospheric environmental quality, water environmental quality, water resource status quo, acoustic environment and environmental livability status quo indices; EPI is the weighted mean of pollutants emission intensity indices in atmospheric environment, water environment and solid waste and ecological environmental pressure index; ERI is the weighted mean of treatment rates/removal rate of different wastes and management indices as staff working for environmental protection etc; and EII is the standardized index of proportion of environmental protection investment to GDP.

The reason of decomposing indicators into three purposes of index is for better explain of the relationship and links of pressure, state and efforts made for the mitigation of environmental pressure and improvement of environmental livability.

3.2 Developing weights

The Analytical Hierarchy Process (AHP), a systematic method allowing comparison between a list of objectives or alternatives using a framework that structures a problem, represents and quantifies its elements, relates those elements to goals, and facilitates evaluation of alternative solutions. It is a special type of the Analytic Network Process which allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved. It is used globally in a wide variety of decision-making situations in fields such as government, business, industry, healthcare, and education[6].

There are three steps when using the process to derive weights for indicators under the environmental liveability index:

- *Structure the issues* within a hierarchy. Typically an AHP hierarchy consists of an overall goal at the top, a group of options or alternatives for reaching the goal at the bottom, and a group of criteria that relate the alternatives to the goal in the middle. In this report, the APH is used to weigh sub-indices and indicators**.**
- To derive the weights, *evaluate the importance of various criteria* in the hierarchy by introducing pairwise comparisons. The sub-indices will be compared to how important they are to decision makers.
- *Derive weights* for each indicator based on these *judgments*, and then test the system.

In terms of the sub-indices, the weight of the atmospheric environment is the highest, 0.17, domestic livability comes second with 0.16, water environment and water resource are both in third place with 0.14, then environmental management and Ecological environment follow with weights of 0.13 and 0.10, and acoustic environment is the lowest, at only 0.07.

4. Application of Environmentally Livable Index

4.1 How to use ELI

The Environmental Livability Index can be used for environmental performance, identification of environmental issues; city comparison, and financial and investment policy analysis. Testing application includes the following steps: ***a. Select pilot cities*:** 33 cities are selected for city comparison analysis and around 5 cities for detailed trend analysis; ***b. Determine benchmarks/targets of indicators*:** For the most of indicators describing "state" such as air, water quality indicators, environmental quality standards can be used as benchmarks, and the targets for policy relevant indicators or indicators for representing society responses are normally set up in various environmental, social and economic development plan; regards some indicators that may not have any standards or targets, some standardization approaches may be used, for example, by using average level of all the targeted cities or international average level as benchmarks; ***c. Analysis and Presentation*:** The analysis will include comparison and trend analysis. ***d. Planning and investment policy implication:*** This step will discuss how to use the analytical results by applying the index for environmental strategy planning and investment prioritization. *e. **Verification***: Officials from some of the selected cities will be invited to discuss and verify the application of the index. The index system may be modified based on the comments from those city representatives.

4.2 Ranking and PSR analysis of ELI

4.2.1Composite urban environmental livability index

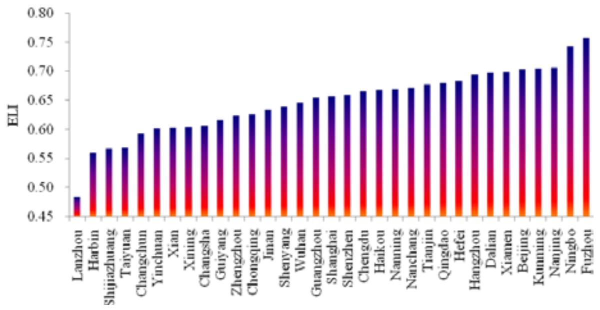
Figure 2, which ranks 33 major Chinese cities according to their environmental livability indices, demonstrates that the ELI is generally higher in southern China, eastern coastal cities and economically developed regions and lower in the north, northwest and less-developed regions. For example, Ningbo, Beijing, Qingdao, and Dalian score better than Taiyuan, Lanzhou, and Harbin. The index is also higher in cities with good natural conditions or large environmental capacity such as Kunming, Xiamen and Hangzhou. Of China's megacities, Beijing has a higher ELI than Shanghai and Guangzhou.

4.2.2Pressure-State-Response Analysis of Urban Water ELI in China

Figure 4 demonstrates the pressure-state-response of different cities. It shows for example that Lanzhou has the highest water environmental pressure and Qingdao the lowest; Ningbo has the best water environmental state and Shenzhen the worst; Zhengzhou has the best water environmental response and Xining the worst.

There is a positive correlation between water environmental condition and response, with cities suffering poor water quality showing a stronger response than those with good water quality. Urban water environmental pressure is affected by upstream pressure as well as local discharge, so the pressure index does not correlate well with the state and response indices.

The water environmental state in cities with low pressure is better in those with high pressure. Cities with poor water environmental state, such as Qingdao, Shenyang and Hefei, have a high response rate, indicating that they attach great importance to protection and treatment of water. Some cities that earned average ratings for environmental pressure and response are rated relatively strongly for environmental state thanks to their naturally high water environmental capacity. Examples include Shanghai and Haikou.



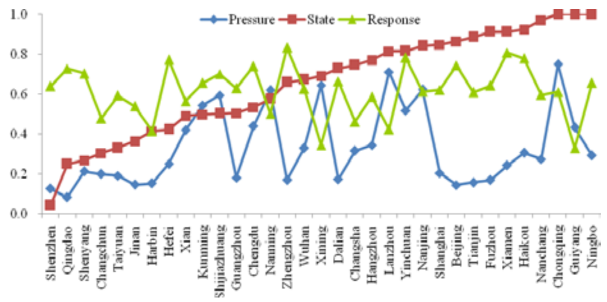


Figure 2 Urban ELI in China **Figure 3 PSR Analysis of urban water ELI in China**

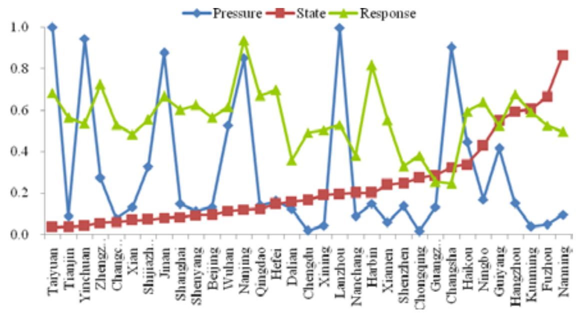
4.2.3 PSR analysis of urban water resource ELI in China

Figure 4 demonstrates the pressure-state-response data for urban water resources. It shows that Taiyuan has the highest water resource environmental pressure and Chongqing the lowest; Nanning has the best water resource environmental state and Taiyuan worst; Nanjing has the best water resource environmental response and Changsha the worst. Of China's megacities, Beijing, Shanghai and Guangzhou all have high water resource pressure. Guangzhou's response is lower than that of Beijing and Shanghai but its state is higher.

In general, pressure and state are positively correlated. This is exemplified by cities such as Taiyuan, Yinchuan, Jinan and Nanjing. Water resource response and state are also positively correlated, as exemplified by Nanning and Fuzhou.

4.2.4 PSR analysis of urban atmospheric ELI in China

Figure 5 shows that Xining has the highest atmospheric pressure and Haikou the lowest. Haikou, however, has the highest atmospheric environmental state, and Urumchi the lowest. Lanzhou scores highest in terms of response and Haikou scores lowest. Of China's megacities, Shanghai has a lower atmospheric response than Beijing and Guangzhou. Cities such as Haikou, and Fuzhou with low pressure rank well in terms of environmental state but poorly in terms of response. Those under high pressure, such as Shijiazhuang, Taiyuan and Chongqing, tend to rank poorly in terms of atmospheric state. Some cities where pressure is relatively low (such as Chengdu and Changsha) nonetheless rank poorly with regard to atmospheric quality because of their weak response.



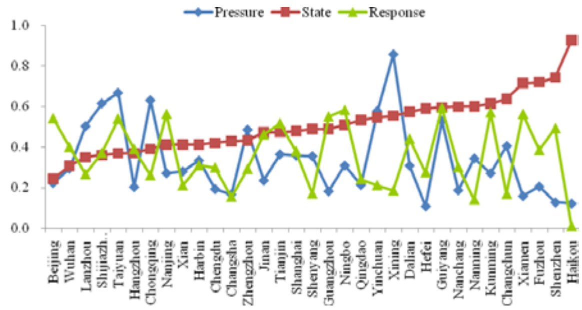
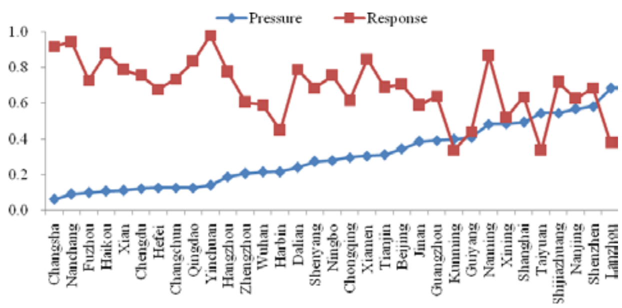


Figure 4 PSR analysis of urban water resource ELI **Figure 5 PSR Analysis of urban atmospheric ELI**

4.2.5 PR analysis of Livability Index in urban solid waste in China

According to Figure 6, Lanzhou has the highest solid waste discharge pressure and Changsha the lowest. Changsha has the strongest disposal response and Kunming and Taiyuan the weakest. Of China's megacities, Beijing's discharge pressure is higher than Shanghai's or Guangzhou's but its response is also higher.

In general, as discharge pressure increases, environmental response capacity decreases. Some cities such as Lanzhou have substantial solid waste pressures but very weak response capacities. These cities must enhance their ability to use, treat and dispose of urban solid waste to improve their environmental livability index.



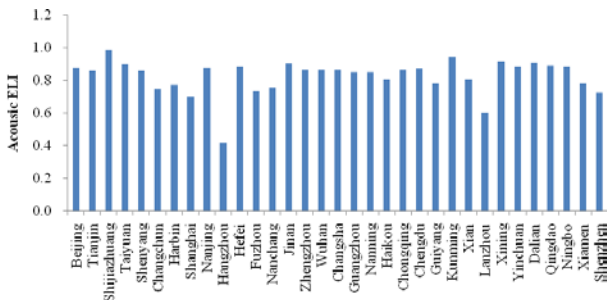


Figure 6 PR analysis of urban solid waste ELI **Figure 7 Ranking of urban noise ELI**

4.2.6 Urban Noise Environmental Livability Indices in China

Figure 7 ranks noise levels for the cities studied. Shijiazhuang ranks the highest and Hangzhou the lowest. Of China's megacities, Beijing has a higher noise environmental livability index than Guangzhou or Shanghai. In general, compared with the other environmental indices discussed in this report, urban acoustic environmental livability in China is high, with the index mostly above 0.6, indicating reasonably good livability in most cities.

4.2.7 Comparative Performance Review of other Environmental Livability Indices in China

Due to the page space limits, the paper cannot list all figures for the evaluation results of Urban ecological environment index, Urban domestic livability and Environmental Management Index. The main comparative performance review conclusions are as follows：

- *Ecological environmental livability indices*: Nanjing is ranked highest and Shijiazhuang lowest. Of megacities, Guangzhou and Beijing rank higher than Shanghai. Ecological environmental problems are serious in Xi'an because of its high population density and ground water depletion.
- *Domestic livability indices*: Nanjing is ranked the highest and Harbin the lowest. Of megacities, Shanghai and Beijing have a higher domestic livability index than Guangzhou. In general, urban domestic livability in the economically developed southern regions (such as Nanjing and Hangzhou) is higher than in northern cities (such as Harbin and Lanzhou).
- *Environmental management livability indices*: Nanjing has the highest livability index in China and Changsha the lowest. Of megacities, Shanghai and Beijing rank more highly than Guangzhou. In general, economically developed regions, such as Nanjing, Beijing, Tianjin, and Chongqing, rank relatively well, indicating that they invest in environmental protection and attach importance to urban environmental management. Some cities (Qingdao and Haikou for example) that rank highly with regard to environmental livability rank poorly for environmental management. Such cities should increase investment in environmental protection and strengthen environmental management in order to raise overall urban environmental livability.

4.3Trend analysis in major cities

From 2000 to 2007, environmental livability in Beijing, Shanghai, Guangzhou, Wuhan and Shenyang rose consistently, as shown in Figure 8. Table 1 compares the five cities, showing their index values and rankings for the years 2000, 2003, 2005 and 2007. Guangzhou recorded the highest improvement rate (45.4%). Over the period, environmental livability in Guangzhou, Beijing and Wuhan rose significantly. Growth in Shanghai and Shenyang was slower.

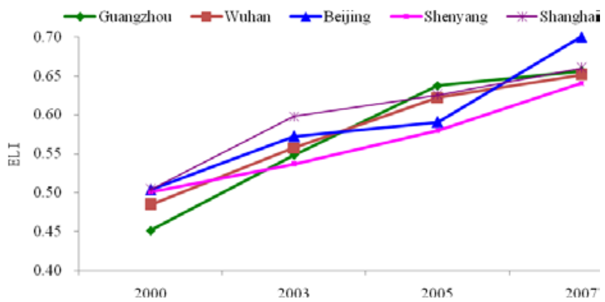


Figure 8 Trend analysis of ELI of major cities

Table 1 Ranking comparison of ELI of major cities

City	2000		2003		2005		2007		Increment Rate (2000 to 2007)/ %
	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	
Guangzhou	0.45	5	0.55	4	0.64	1	0.66	3	45.4
Wuhan	0.48	4	0.56	3	0.62	3	0.65	4	34.4
Beijing	0.50	2	0.57	2	0.59	4	0.70	1	32.9
Shenyang	0.50	3	0.54	5	0.58	5	0.64	5	27.8
Shanghai	0.50	1	0.60	1	0.63	2	0.66	2	24.3

4.3.1Beijing

Figure 9a shows that in 2000 the main environmental problems in Beijing were in the areas of water environment, water resources, air quality and solid waste. By 2007 (Figure 9b) its water environment index had risen from 0.43 to 0.82, water resources from 0.32 to 0.49, air quality from 0.23 to 0.52 and solid waste from 0.42 to 0.68, rising by 91.2%, 51.8%, 125.3% and 62.4% respectively. Despite these improvements, water resource and air quality indicators remain poor because Beijing has low per capita water resources, high concentrations of nitrogen oxide and limited ability to remove these. To tackle such problems, Beijing should strengthen water resource management and air quality controls.

4.3.2Shanghai

Figure 10a shows that Shanghai's major environmental problems in 2000 related to water resources and environment, and air quality. All had improved markedly by 2007, as shown in Figure 10b. However, water resource and air quality remained weak when compared to other indicators because of Shanghai's low per capita water resource base, heavy sulfur dioxide pollution and limited ability to remove pollutants at source. Solid waste and ecological indices during the seven-year period fell by 15.7% and 24.6% respectively as urban domestic waste production increased but treatment capacity lagged behind. Shanghai must therefore focus attention on water resources, air quality, and the management of solid waste.

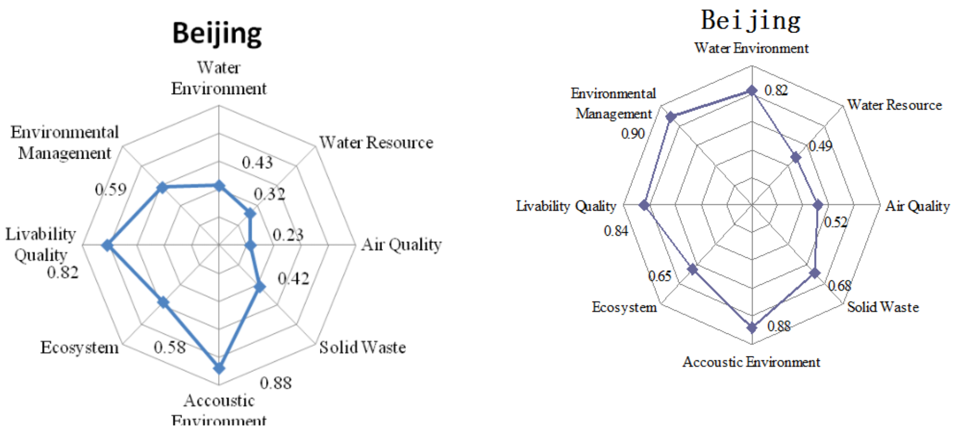


Figure a Figure b

Figure 9 Trend analysis for Beijing

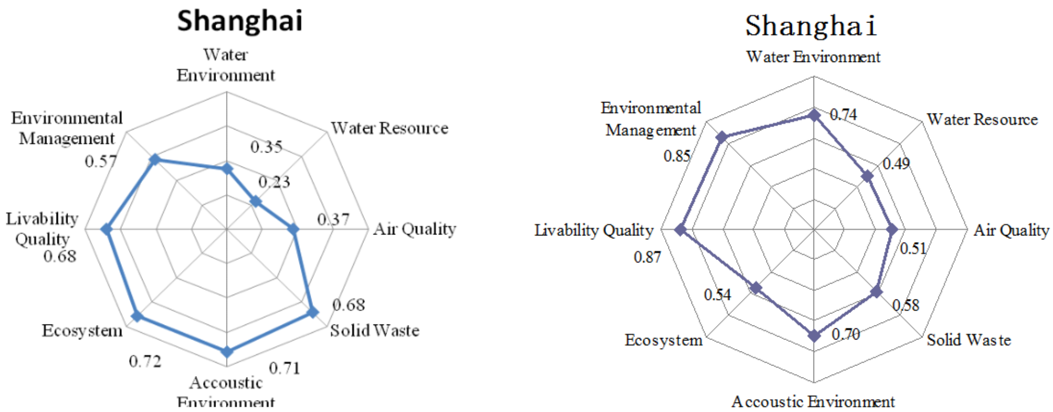


Figure a Figure b

Figure 10 Trend analysis for Shanghai

4.3.3Guangzhou

Figure 11a indicates that in 2000 Guangzhou's water environment, water resource, air quality, solid waste and environmental management indices were all low. By 2007, as shown in Figure 28b, many of these indicators had risen substantially: water environment, water resource, air quality, solid waste and environmental management indices had risen by 101.9%, 82.1%, 68%, 58.3% and 82.3% respectively. The city's water resource indicator remains low because Guangzhou has low per capita water resources and low water recycling rates. Further work is needed in this area.

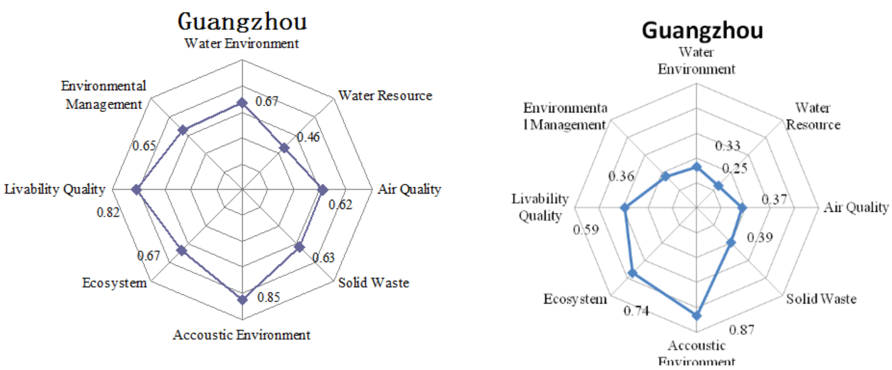


Figure a Figure b

Figure 11 Trend analysis for Guangzhou

From 2000 to 2007, Guangzhou’s ecological environmental livability indicator dropped significantly, showing that the city must also pay more attention to ecological environmental management.

4.3.4Wuhan

Figure 12a demonstrates that Wuhan’s key environmental problems in 2000 were related to its water environment, water resources and air quality. By 2007, as shown in Figure 12b, it had recorded significant improvements in all of these areas, most particularly in relation to water environment (where the index climbed by 218%).

Nonetheless, Wuhan’s water resource and air quality indicators remain low because of low per capita water resources, heavy sulfur dioxide and particulate pollution, and its limited ability to treat nitrogen oxides. Wuhan must continue to focus on the management of water resources (by advocating for more economical use of water and encouraging improved water circulating utilization rates) and strengthen the treatment of atmospheric pollution.

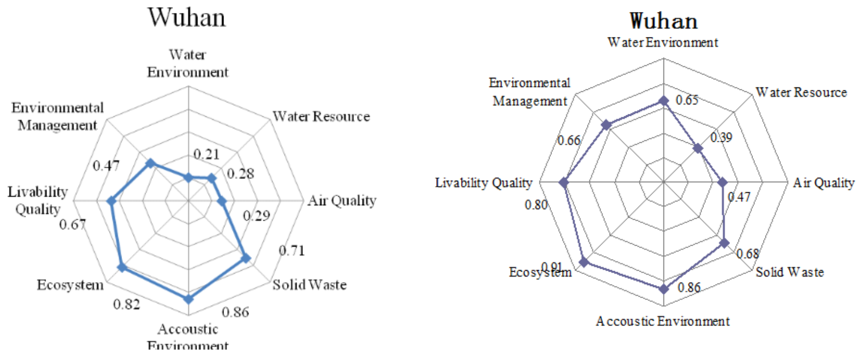


Figure a

Figure b

Figure 12 Trend analysis for Wuhan

4.3.5Shenyang

Figure 13a shows that in 2000 the main environmental problems facing Shenyang related to its water environment, water resources and air quality. By 2007, indicators in all of these areas had improved, with particularly strong growth in water environment (150%). When compared with other cities, however, indicators are weak thanks to Shenyang’s poor surface water quality, low per capita water resources, high sulfur dioxide and particulate concentration, and limited ability to remove major atmospheric pollutants.

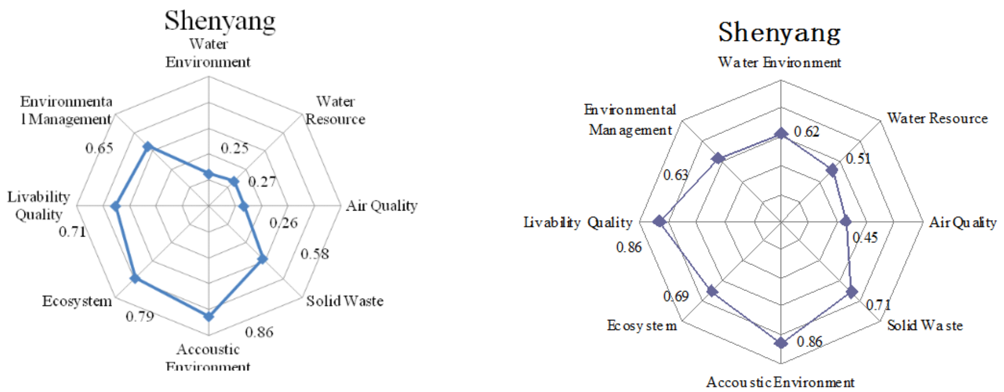


Figure a

Figure b

Figure 13 Trend analysis for Shenyang

Its ecological environment and environmental management indices dropped over the study period by 13.3% and 3.81% respectively due to rising groundwater exploitation and insufficient investment in protection of the urban environment. Shenyang must increase investment in environmental protection and continue to focus on improving its water environment, water resources, air quality controls and ecological environment.

4.4 Effect of urban environmental investment on environmental state

4.4.1Relationship of ESI, EPI and EII in major cities

Urban environmental quality is mainly affected by environmental pressure and the level of environmental pollution control， the paper had an analysis about the relationship among ESI, EPI and EII. As shown in Figure 13, ESI has a positive correlation with EPI and a negative correlation with EII in most cities. Figure 14 shows that the environmental pressure of megacities as Beijing, Shanghai, Tianjin, Guangzhou and Shenzhen are almost equivalent. Although environmental protection investment index in Guangzhou and Shenzhen is lower than that in the other cities, their environmental state is better than Beijing, Shanghai and Tianjin.

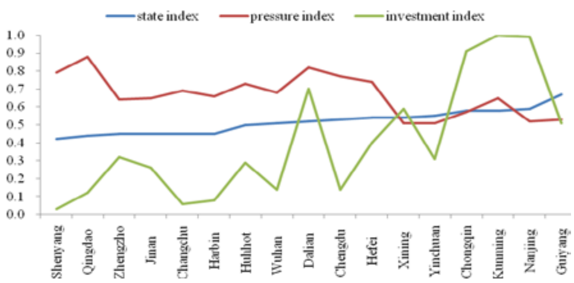


Figure 13 ESI, EPI and EII of major cities

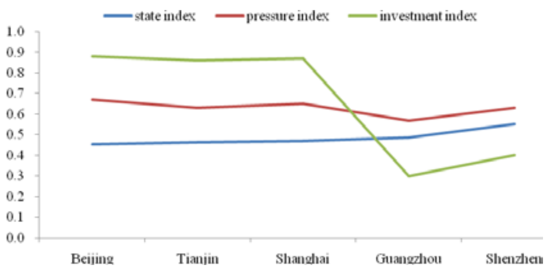


Figure 14 ESI, EPI and EII of megacities

4.4.2 Effect of urban environmental investment

Using the data of 33 cities, urban environmental state index S is dependent variable and urban environmental pressure index P and urban environmental investment index F are independent variable, the following linear model is established:

$$S=0.678F-0.413P+0.549 \qquad (1)$$

The test result of the above model shows that R^2 of the model is 40%, indicating that 40% environmental state change can be explained by the variables of environmental pressure and environmental protection investment; both model and coefficient passed the significance test. At the same time, it is known from the residual plot that standardized residual does not have heteroscedasticity and there is not a linear relation between residual and the variable of environmental state, which conforms to the assumption of the model. The model reveals the following conclusion:

- EPI has a negative correlation with with ESI of urban environmental quality. As urban environmental pressure increases, environmental state falls and its marginal influence coefficient is 0.413.
- EII has a positive correlation with ESI of urban environmental quality. As urban environmental protection investment increases, environmental quality rises and its marginal influence coefficient is 0.678.
- It is known from the model that although the absolute value of the variable coefficient of environmental protection investment is greater than that of the variable coefficient of environmental pressure, the absolute value of its standardization coefficient is smaller than that of the environmental pressure coefficient, indicating that the influence of environmental pressure variable on urban environmental state is greater than environmental investment coefficient. Therefore, the emphasis of present urban environmental protection investment should be still put on the reduction of pollution emission, i.e. that mitigating urban environmental pressure and reducing pollution emission are still the priority tasks of most Chinese cities. Invest on the comprehensive

cleaning and beautification of urban environment and further improvement of environmental quality should be on the second place.

5. Conclusions

The environmental liveability index is a useful tool for assessing liveability, monitoring trends, policy analysis and planning, and communicating to the public, but it can do these things only if it is integrated into China's environmental management framework. However, its practical application still has a long way to go due to the effectiveness of ELI itself and the possible political barriers.

5.1Functions and potential applications

Based on a combination of PSR model and theme based approach, environmental livability indicators are proposed and weights for aggregating these indicators into a composite index are established. Further, the test application of the ELI is carried out for 33 PRC cities including Beijing, Shanghai, Taiyuan and Lanzhou etc. The application demonstrates how the environmental livability indicators and its aggregated index (ELI) can be used for (i) providing a tool for assessing the currently environmental livability status and for identifying priority environmental issues related to city livability; (ii) monitoring environmental pollution control and natural resource management trends, and (iii) hereby providing a basis for analyzing the effectiveness of the past and current environmental policies; (iv) comparing or ranking environmental performance among the selected cities, which may spur pressure on local government for improving the city environmental livability; (v) providing a baseline or advice for policy making or environmental planning such as environmental investment plan; (vi) facilitating public communication.

5.2Shortcomings of the Current ELI system

Although the test application shows that the ELI system can be used as a tool for environmental livability evaluation and policy analysis, but there are many methodological uncertainties regarding establishing ELI and institutional barriers for applying ELI for policy making. The methodological uncertainties include: (i) The aggregated ELI and its indicators are usually constructed in a manageable size by scarifying details. Further some of aspects on environmental livability may not be measurable in a quantitative way. Policy analysis and making are normally required to fully understand the phenomenon or issues, which may require other qualitative and scientific information such as driving forces and natural background for explaining trends or issues, therefore the ELI system should be used as only one of tools, that is, as a tool for helping reveal trends and draw attention to problems that require further analysis and possible actions. (ii) Implicit assumptions in selection of indicators and calculation of weights. These indicators and weights needs to be further tested and verified in the future applications.

The institutional barriers are: (i) data availability and data quality. The data availability and data quality is a critical issue for applying the ELI system. For current testing application, data comes from different sources. Some of data are from research reports, that means these data are not regularly measured, also most of data are not available for medium and small cities. The data availability has made problems in selection of appropriate indicators, which may result in failing to measure important aspects of environmental livability and also it limits the possibility of applying it in small and medium cities. Lack of data availability and data quality will cause problems to give unbiased or complete picture of environmental livability, that may lead to serious problems on policy decision. (ii) benchmarks and targets. Environmental standards and national environmental planning target can be used as benchmarks and targets for some of the indicators, but it is difficult to define a common recognized benchmarks and targets for standardizing some of the indicators such as emission per GDP etc.

5.3Future Directions

International Experience shows that indicators similar to environmental livability indicators are cost-effective and powerful tools for tracking environmental progress, providing policy feedback and measuring environmental performance. Also the testing application shows the potential possibility of applying these indicators for PRC city environmental improvement. However, international experiences and this testing application also shows that development of the ELI is a dynamic process, which means that the ELI requires constant improvement through its future application and within the improvement of the data availability and data quality. Number of future works both technical and institutional are recommended as follow:

- Establishment of monitoring and data collection system. Data availability and data quality are critical for applying the ELI system. It is suggested to set up a designated department for the monitoring and data collection or assigned it to an existing department within current environmental organization, at the national and city levels, in cooperation with other relevant institutions such as economic and statistical institutions. The department at the national level will provide standardized measurement approaches and ensure the collected data are comparable. The local level departments will be responsible for monitoring and collecting data and timely reporting the data to the national level.
- Promotion of its application in PRC cities and continuous improvement of the ELI indicators system. To promote its application, a demonstration and training problem is strongly suggested as a follow up program for demonstrating and training city governments on the application of the ELI system for monitoring, evaluation of environmental livability and improving their policy analysis capability by using the ELI system. The feedback from these demonstration and training program will be used for further improving the ELI system.
- Linking to the five-year plan. Environmental five-year plan is a key tool for national and local environmental protection. In principle ELI can provide methodologies for identifying environmental issues, evaluating the effectiveness of the five year plan and providing indicators to monitor and evaluate the implementation of the five year plan. However further work needs to be done on how the ELI can be used as a tool for environmental five year plan and performance evaluation
- Propose benchmark-linked investment assessments with ELI system. There are three main types of environmental protection investment in China. In: (i) the construction of urban environmental infrastructure; (ii) the treatment of long-standing industrial pollution sources; and (iii) environmental protection of new projects. However, the absence of a unified definition of, or statistical methodology for, environmental protection investment damages data accuracy and creates problems when choosing assessment indicators and methods to measure the effects of this investment. So the presented analysis in section 4.4 is still at elementary and rough stage and more efforts should be exerted both for data gap and analytic methodologies.

Reference

[1]UN_HABITAT Global Urban Observatory Country and City Projects, URL: http://ww2.unhabitat.org/programmes/guo/country and city projects.asp

[2]UN Department for Economic and Social Affairs, Division of Sustainable Development, Core Publications, Agenda 21, URL: http://www.un.org/esa/dsd/agenda21/resagenda2100.shtml

[3]UNDP Human Development Reports 2009, URL: http://hdrstats.undp.org/en/indicators/3.html

[4]P.Newton, J. Flood, M. Berry, K. Bhatia, S. Brown, A. Cabelli, J. Gomboso, J. Higgins, T. Richardson and V. Ritchie (1998) Environmental Indicators for National State of the Environment Reporting – Human Settlements, Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra.

[5]P. Newton, Urban Indicators and the Management of Cities. URL: http://www.adb.org/Documents/Books/CitiesDataBook/02chapter2.pdf

[6]Thomas L. Saaty and Luis G. Vargas, 1994, Decision Making in Economic, Social and Technological Environments, RWS Publications, Pittsburgh, USA

Fishery Subsidies, Illegal Fuel Trading and Conservation

Chih-Ming Hung

Assistant Research Fellow, Division of Taiwan Economy, Chung-Hua Institution for Economic Research, 75 Chang-Hsing St., Taipei, Taiwan 10672, email: cmhung@cier.edu.tw

Yung-ho Weng

Professor, Department of Economics, National Chengchi University, 64, Sec. 2, Tz-nan Rd., Wenshan, Taipei 116, Taiwan, email: yweng@nccu.edu.tw

Abstract: This paper incorporates the illegal fuel trading behavior to examine the changes of fishery subsidy rate, detection effort and fish price on the level of fishing, illegal fuel trading and fish biomass. The corresponding effects on the profit of fisherman and profit of the oil company which supply the raw fuel to the fishery are also examined. The subsidy policy always benefits the fisherman and oil company but at the cost of the biomass loss. Second, the increase in the detection effort leads more fishing and less illegal activities, and less fish biomass. The increase in the detection effort encourages the legal activity on fishing, but punishes the illegal activity on fuel trading. Iironically, the increase in detection effort also hurts the profit of oil company and the fish biomass. Finally, the increase in the fish price leads to similar results with those in the increase in the detection effort, but only one qualitative difference is that the increase in fish price benefits the profit of oil company.

1. Introduction

Subsidies for fisheries have attracted a lot of attention from economists and biologists (Sharp and Sumaila, 2009; Sumaila, et al. 2008; Tyedmers et al, 2005; Lindebo, 2005; Schrank and Keithly 1999), and many of them agreed that most subsidies are harmful to the ocean environment (Sumaila, et al. 2008; OECD 2006; UNEP, 2004; Sanchirico, 2003). With decreasing fishing cost, this results directly or indirectly in the build-up of excessive fishing capacity and effort, leading to the over-exploitation of fishery resources, and undermining future economic benefits. In particular, subsidies for fuel price which constitutes a substantial component of the cost fishing (Sumaila, et al. 2008; Tyedmers et al, 2005), promote the use of active, fuel-intensive fishing techniques such as dredging, beam trawling and bottom trawling which are detrimental to the marine environment than passive fishing techniques. In addition, the increase in fuel-intensive fisheries also leads to a substantial increase in CO_2 emissions from fishing vessels.

Another story regarding fuel subsidies worthwhile to be noticed is that subsidies for fuel price create incentives for smuggling and illegal oil trading. For example, in Taiwan, price subsidy for fuel (14% per kiloliter) has increased illegal oil trading activities, and those fuels usually flows into the tank of vehicle on land. When the subsidized fuel price is lower than that without subsidized, the price wedge provides people with incentives to trade, even though this kind of transaction is not allowed legally. Given the existence of smuggling and illegal fuel trading, we further ask some questions: firstly will the increased in subsidy pull the fishermen away from fishing, and what are the effects of fuel subsidy on the fish biomass or biological conservation? Secondly, to decrease illegal trading some enforcement measures must be implemented, such as detection and punishment on those illegal activities. What would be the effects on the total profits of the fisherman and on the fish resource conservation, if the detection efforts increase? Thirdly, what are the effects of fish price changes on the illegal fuel trading and fish resource? To our knowledge, the above questions are not fully explored in the existing literature.

This paper incorporates the illegal fuel trading behavior to examine the changes of fishery subsidy rate, detection effort and fish price on the level of fishing, illegal fuel trading and fish biomass. The corresponding effects on the profit of fisherman and profit of the oil company which supply the raw fuel to the fishery are also examined. These questions are examined through a three-stage model in which the sole oil company chooses the fuel price to maximize its profit in the first stage, the fisherman chooses the level of fuel for fishing and for illegal trading with illegal trader in the second stage, and then the oil trader chooses the price to maximize its profit in the oil black market in the third stage. The game is solved by backward induction.

The remainder of the paper is organized as follows. Section 2 sets up the basic model. Section 3 examines the effects of increase in the subsidy rate, detection rate and fish price. Section 4 concludes.

2. The Basic Model

In what follows we first characterize the basic fishery model followed by Ruseski (1998), and Quinn and Ruseski (2001), and then incorporate the basic elements in characterizing the illegal behavior (Sumaila and Keith, 2006; Charles et al, 1999). In addition, we assume that there is sole oil company supplying raw fuel to the fishery and assume only one fisherman engages in fishing and illegal fuel trading. The fisherman resells the fuel to the middleman and, again, he sells the illegal fuel to the transportation sector. In order to decrease the illegal fuel trading, the authority can increase its detection effort and increase penalty on the illegal activity.

Following the general fishery literature, we assume there is a single fish stock of size B that follows the Schafer model, and its dynamic equation is

$$\frac{dB}{dt} = rB\left(1 - \frac{B}{K}\right) - h. \tag{1}$$

where the first term on the right hand side is the natural growth function, r is the intrinsic rate of growth and K is the carrying capacity of the fishing ground, and the second term is the harvest level. The harvest function for fisherman is linear in its boat fuel usage x and the size of the stock,

$$h = qxB, \tag{2}$$

where q is the catchability coefficient.

Following Ruseski (1998), and Quinn and Ruseski (2001), we assume that objective functions are based on steady-state values, the dynamic equation can be set equal to zero and combined with the natural growth and harvest functions to reveal the unique steady-state size of the fish stock as follows:

$$B = \frac{K}{r}(r - qx). \tag{3}$$

Next the illegal fuel trading behavior in the vertically market structure is characterized. It is assumed that the inverse demand function for the smuggling fuel y in the transportation sector is:

$$P^M = a - by. \tag{4}$$

where P^M is the demand price for the fuel in the transportation sector, and $a, b > 0$. In the third stage of the three-stage game developed here, the middleman chooses the trading price to maximize his profit from illegal trading with transportation sector, facing the fuel price P^I chosen by the fishery who engages in illegal fuel trading. It follows that:

$$\max_{P^M} \quad \Pi^T = \left(P^M - P^I\right) y. \tag{5}$$

by the first-order condition in eq. (5), the inverse demand function that fisherman faces is

$$P^I = a - 2by. \tag{6}$$

Moving back to the second stage of the game, the fisherman chooses fuel usage x on the fishing activity and fuel resold y to the middleman to maximize its aggregate profits as follows:

$$\max_{x,y} \quad \Pi = \Pi^F + \Pi^O, \tag{7}$$

where

$$\Pi^F = \bar{P}h - \left(1-\alpha\right) P^O x, \tag{8}$$

$$\Pi^I = P^I y - \left(1-\alpha\right) P^O y - \theta F. \tag{9}$$

where Π^F and Π^I are the rent from fishing and profit from illegal fuel trading, respectively. The $\bar{P}$ is the competitive fish price which is assumed to be constant, P^O is the price of fuel that chosen by the oil company, and α is the subsidy rate, $\alpha \in [0,1]$. The θ is the detection rate, $\theta \in [0,1]$, and F is fined once caught and assumed to be $F = y^2/2$, thus the expected fine is $\theta F = \theta y^2/2$.

By differentiating the eq. (7) with respect to x and y as well as simultaneously solve the two first-order conditions derived previously, we have the optimal solutions in the second stage game such that:

$$x = \frac{r\left[K\bar{P}q - P^O(1-\alpha)\right]}{2K\bar{P}q^2}, \tag{10}$$

$$y = \frac{a - P^O(1-\alpha)}{4b+\theta}. \tag{11}$$

From (10) and (11), we can readily find that the increase in the price of raw fuel decreases x and y. By aggregating x and y in eqs. (10) and (11), we obtained the inverse demand function for the raw fuel in the first stage such that:

$$P^O = \Phi + \Omega(x+y), \tag{12}$$

where

$$\Phi = \frac{K\bar{P}q\left[2aq + r(4b+\theta)\right]}{(1-\alpha)\Delta} > 0, \tag{13}$$

$$\Omega = -\frac{2K\bar{P}q^2(4b+\theta)}{(1-\alpha)\Delta} < 0, \tag{14}$$

$$\Delta = 2K\bar{P}q^2 + r(4b+\theta) > 0.$$

From eqs. (12), (13) and (14), it is interesting to find that the policy parameter, (α, θ), biological parameter, ($\bar{K}$, q, r), and market parameter ($\bar{P}$, a, b) are grouped into the intersection term Φ and slope term Ω in the eq. (12), therefore when any changes of these parameter will change the intersection and slope terms in the demand function faced by the oil company. As the intersection term Φ increases, the market size for the raw fuel increases and vice versa. As the slope term of the demand function increases, the price elasticity for the raw fuel increases. In other words, it empowers the oil company to determine the price. We will then examine the effects of changes in policy parameters α and θ, as well as market parameter $\bar{P}$ later.

Finally, let us turn to the choice of raw fuel price by the oil company in the first stage of the three-stage game. The maximization problem for the oil company is as follows:

$$\max_{P^O} \quad \Pi^O = \left(P^O - c\right)\left(x + y\right). \tag{15}$$

where c is the unit cost of production. By substituting x and y in eqs. (10) and (11) into (15) and differentiating (15) with respect to P^O, we have the optimal raw fuel price in the first-stage as follows:

$$P^{O^*} = \frac{K\bar{P}q\left[2aq + r\left(4b+\theta\right)\right]}{2\left(1-\alpha\right)\Delta} + \frac{c}{2}. \tag{16}$$

By substituting the optimal raw fuel price in eqs. (16) back into eqs. (10), (11), (3) and (2), we have the optimal value in reduced-form as follows:

$$x^* = \frac{r}{4}\left[\frac{1}{q} - \frac{(1-\alpha)c}{K\bar{P}q^2}\right] - \frac{r\left(a - K\bar{P}q\right)}{2\Delta}, \tag{17}$$

$$y^* = \frac{a-(1-\alpha)c}{2\left(4b+\theta\right)} + \frac{r\left(a - K\bar{P}q\right)}{2\Delta}, \tag{18}$$

$$B^* = \frac{3K\bar{P}q-(1-\alpha)c}{4\bar{P}q} + \frac{Kq\left(a - K\bar{P}q\right)}{2\Delta}, \tag{19}$$

$$h^* = qx^*B^*. \tag{20}$$

3. Analysis

In what follows, we are going to analyze the effects of the increase in the subsidy rate, detection rate and the fish price accordingly. In each subsection, the effects on the fuel usage level on fishing, illegal fuel trading and fish biomass are analyzed first, and the effects on the profits of fisherman and oil company are examined in turn.

3.1 Subsidy Effects

Differentiating eqs. (17), (18) and (19) with respect to subsidy rate α leads to :

$$\frac{\partial x^*}{\partial \alpha} = \frac{rc}{4K\bar{P}q^2} > 0, \tag{21}$$

$$\frac{\partial y^*}{\partial \alpha} = \frac{c}{8b+2\theta} > 0, \tag{22}$$

$$\frac{\partial B^*}{\partial \alpha} = -\frac{c}{4\bar{P}q^2} < 0. \tag{23}$$

It is observed from eqs. (21) and (22) that a small increase in the subsidy rises fuel usage both on the fishing and illegal trading. On the one hand, the increase in the subsidy decrease the marginal cost in both legal and illegal activities and encourages both fishing and smuggling at the same time. On the other hand, the increase in the fuel usage on the fishing decreases the steady-state fish biomass as shown in eq. (23).

Now let us consider the effects of a small increase in subsidy on the profits of oil company:

$$\frac{\partial \Pi^{O*}}{\partial \alpha} = \left[\frac{\partial \Phi}{\partial \alpha} + \left(x^* + y^* \right) \frac{\partial \Omega}{\partial \alpha} \right] \left(x^* + y^* \right) > 0, \tag{24}$$

where

$$\frac{\partial \Phi}{\partial \alpha} = \frac{K\bar{P}q\left[2aq + r\left(4b+\theta\right)\right]}{\left(1-\alpha\right)^2 \Delta} > 0, \tag{25}$$

$$\frac{\partial \Omega}{\partial \alpha} = -\frac{2K\bar{P}q^2\left(4b+\theta\right)}{\left(1-\alpha\right)^2 \Delta} < 0. \tag{26}$$

By the envelope theorem (Varian, 1992), it can be seen from the eq. (24) that the effects of increase in subsidy on the profit of oil company is positive. The increase in subsidy rate increase the market size Φ as shown in eq. (25), and makes the slope of demand function for raw fuel Ω more steeper, i.e., ($-\partial\Omega/\partial\alpha > 0$), results in more profits for the oil company. The effects of increase in subsidy rate on the rent of fishing and profit on the fuel trading are demonstrated as follows:

$$\frac{\partial \Pi^{F*}}{\partial \alpha} = P^{O*}x^* - \left(1-\alpha\right)x^* \left[\frac{\partial \Phi}{\partial \alpha} + \frac{\partial \Omega}{\partial \alpha}\left(x^* + y^*\right) + \Omega \frac{\partial y^*}{\partial \alpha} \right] > 0, \tag{27}$$

$$\frac{\partial \Pi^{I*}}{\partial \alpha} = P^{O*} y^* - (1-\alpha) y^* \left[\frac{\partial \Phi}{\partial \alpha} + \frac{\partial \Omega}{\partial \alpha} (x^* + y^*) + \Omega \frac{\partial x^*}{\partial \alpha} \right] > 0, \qquad (28)$$

From the first term in eq. (27) it can be found that the direct effect of small increase in the subsidy rate increases the rent on fishing, while the indirect effect of small increase in the subsidy, the second term in eq. (27), is negative. The indirect effect comes from the increase in the subsidy rate strengths the monopoly power to raise fuel price which increases the marginal cost of fisherman. It can be found that the direct effect dominates the indirect effect, such that the increase in the subsidy rate increases the rent of fishing. By the same reason, the increase in the subsidy rate increases the profits of illegal fuel trading as expressed in eq. (28). The effects of the increase in subsidy on fuel price are summarized as follows:

Proposition 1: *An increase in the subsidy on the fuel price increases the equilibrium fuel usage both on the fishing and illegal trading, however decreases the steady-state fish biomass. In addition, the equilibrium rent for fishing, the profit for illegal fuel trading by fisherman and profit for the oil company also increase.*

3.2 Detection Effects

Differentiating eqs. (17), (18) and (19) with respect to subsidy rate θ leads to :

$$\frac{\partial x^*}{\partial \theta} = \frac{(a - K\bar{P}q) r^2}{2\Delta^2} > 0, \qquad (29)$$

$$\frac{\partial y^*}{\partial \theta} = -\frac{1}{2} \left[\frac{a - (1-\alpha)c}{(4b+\theta)^2} \right] - \frac{(a - K\bar{P}q) r^2}{2\Delta^2} < 0, \qquad (30)$$

$$\frac{\partial B^*}{\partial \theta} = -\frac{Kq(a - K\bar{P}q) r}{2\Delta^2} < 0. \qquad (31)$$

It is observed from eq. (29) that a small increase in the detection effort increases fuel usage, while from eq. (30) that increased effort decreases the illegal fuel trading. The additional detection effort increases the marginal cost in illegal fuel trading, thus lowers the fuel trading. In order to maximize aggregate profits, the fisherman turns its effort on the fishing such that increases the fuel usage. However, the policy to maintain legal oil market order leads to the decline of fish biomass as expressed in eq. (31).

Let us consider the effects of a small increase in subsidy on the profits of oil company first:

$$\frac{\partial \Pi^{O*}}{\partial \theta} = \left[\frac{\partial \Phi}{\partial \theta} + \left(x^* + y^* \right) \frac{\partial \Omega}{\partial \theta} \right] \left(x^* + y^* \right) < 0, \tag{32}$$

where

$$\frac{\partial \Phi}{\partial \theta} = -\frac{2K\overline{P}q^2 \left(a - K\overline{P}q \right) r}{\left(1-\alpha\right)\Delta} < 0, \tag{33}$$

$$\frac{\partial \Omega}{\partial \theta} = -\frac{4K^2\overline{P}^2 q^4}{\left(1-\alpha\right)\Delta} < 0. \tag{34}$$

By the envelope theorem, it can be seen from eq. (32) that the effect of additional detection effort on the profit of oil company is negative. The increase in detection rate decreases the market size Φ as shown in eq. (33), but makes the slope of demand function for raw fuel Ω more steeper, i.e., ($-\partial\Omega/\partial\theta > 0$), the former negative effect dominates the later positive effect results in less profits for the oil company. The effects of increase in detection rate on the rent of fishing and profit on the fuel trading are demonstrated as follows:

$$\frac{\partial \Pi^{F*}}{\partial \theta} = -(1-\alpha)x^*\left[\frac{\partial \Phi}{\partial \theta} + \frac{\partial \Omega}{\partial \theta}\left(x^* + y^*\right) + \Omega\frac{\partial y^*}{\partial \theta}\right] > 0, \quad (35)$$

$$\frac{\partial \Pi^{I*}}{\partial \theta} = -\theta y^* - (1-\alpha)y^*\left[\frac{\partial \Phi}{\partial \theta} + \frac{\partial \Omega}{\partial \theta}\left(x^* + y^*\right) + \Omega\frac{\partial x^*}{\partial \theta}\right] < 0. \quad (36)$$

Eq. (35) shows that the effect of small increase in the detection rate on the rent of fishing is positive, which is reflected on the shrinking power of oil company to set higher price, thus the increase in the detection rate decrease the raw price, lowering the marginal cost of fishing, which increases the profit of fishing. The first term of the eq. (36) tells us that the direct effect of small increase in the detection rate decreases the profit on illegal fuel trading, while second term of the indirect effect of small increase in the detection rate increase the profit on fuel trading because the raw fuel price is decreasing with increase in detection rate. The direct effect outweighs the indirect effect leads to the outcome in (36).

Proposition 2: *An increase in the detection effort on illegal fuel trading increases the equilibrium fuel usage on the fishing but decreases the fuel usage on the illegal fuel trading. However it also decreases the steady-state fish biomass. In addition, the equilibrium rent for fishing increases, but the profit for illegal fuel trading by fisherman and profit for the oil company decrease.*

3.3 Fish Price Effects

Differentiating eqs. (17), (18) and (19) with respect to fish price $\bar{P}$ leads to :

$$\frac{\partial x^*}{\partial \bar{P}} = \frac{(1-\alpha)rc}{4K\bar{P}^2q^2} + \frac{Kqr\left[2aq + r(4b+\theta)\right]}{2\Delta^2} > 0, \tag{37}$$

$$\frac{\partial y^*}{\partial \bar{P}} = -\frac{Kqr\left[2aq + r(4b+\theta)\right]}{2\Delta^2} < 0, \tag{38}$$

$$\frac{\partial B^*}{\partial \bar{P}} = -\left[\frac{(1-\alpha)c}{\bar{P}^2} + \frac{2K^2q^3\left(2aq + r(4b+\theta)\right)}{\Delta^2}\right] \Big/ 4q < 0. \tag{39}$$

It is observed from eq. (37) that a small increase in the fish price increases fuel usage on the sea, while from eq. (38) that the increase in the fish price decreases the illegal fuel trading. The increase in the fish price increases the marginal benefit in fishing, thus increases the fuel usage on the sea. In order to maximize aggregate profits, the fisherman pulls its resource from illegal activity such that decreases fuel usage on the fuel trading. However, the higher price also leads to the decreasing fish biomass as shown in eq. (39).

Next we analyze the effects of a small increase in fish price on the profits of oil company first and fisherman after:

$$\frac{\partial \Pi^{O*}}{\partial \bar{P}} = \left[\frac{\partial \Phi}{\partial \bar{P}} + \left(x^* + y^*\right)\frac{\partial \Omega}{\partial \bar{P}}\right]\left(x^* + y^*\right) > 0. \tag{40}$$

where

$$\frac{\partial \Phi}{\partial \bar{P}} = \frac{Kqr(4b+\theta)\left[2aq + r(4b+\theta)\right]}{(1-\alpha)\Delta} > 0, \tag{41}$$

$$\frac{\partial \Omega}{\partial \bar{P}} = -\frac{2Kq^2r(4b+\theta)^2}{(1-\alpha)\Delta} < 0. \tag{42}$$

By the envelope theorem, it can be seen from eq. (40) that the effect of increase in the fish price on the profit of oil company is positive. The increase in fish price increases the market size Φ as shown in eq. (41), and makes the slope of demand function for raw fuel Ω more steeper, i.e., ($-\partial\Omega/\partial\bar{P} > 0$), Both effects increase the profits of the oil company. We then examine the effects of increase in the fish price on the rent of fishing and the profit on the fuel trading as follows:

$$\frac{\partial \Pi^{F*}}{\partial \bar{P}} = h^* - (1-\alpha)x^*\left[\frac{\partial\Phi}{\partial\bar{P}} + \frac{\partial\Omega}{\partial\bar{P}}\left(x^* + y^*\right) + \Omega\frac{\partial y^*}{\partial\bar{P}}\right] > 0, \tag{43}$$

$$\frac{\partial \Pi^{I*}}{\partial \bar{P}} = -(1-\alpha)y^*\left[\frac{\partial\Phi}{\partial\bar{P}} + \frac{\partial\Omega}{\partial\bar{P}}\left(x^* + y^*\right) + \Omega\frac{\partial x^*}{\partial\bar{P}}\right] < 0. \tag{44}$$

Eq. (43) shows that the direct effect of small increase in the fish price on the rent of fishing outweighs the negative indirect effect that decrease the rent which comes from that oil company is also equipped with its price determination power from the increase in the fish price. Eq. (44) shows that rising the fish price decreases the profit of illegal fuel trading, because the oil company rises its price due to the increased fish price which leads to the increase in the marginal cost of fuel trading.

Proposition 3: *An increase in the fish price increases the equilibrium fuel usage on the fishing but decreases the fuel usage on the illegal fuel trading. However it also decreases the steady-state fish biomass. Furthermore, the equilibrium rent for fishing and profits for oil company increase, but the profit for the illegal fuel trading declines.*

4. Conclusion

This paper incorporates the illegal fuel trading behavior in a three-stage model to examine the fishery subsidy policy on the fishing, illegal fuel trading and fish biomass. In the model developed here, the subsidy policy is accompanied by the enforcement efforts exercised by the authority through detection and punishment. Therefore the effects of detection effort are also examined.

We first find that the increase in the subsidy rate results in more fishing and more illegal fuel trading, and less fish biomass; The subsidy policy always benefits the fisherman and oil company but at the cost of the biomass loss. Second, we find that the increase in the detection effort leads more fishing and less illegal activities, and less fish biomass. The increase in the detection effort encourages the legal activity on fishing, but punishes the illegal activity on fuel trading. Ironically, the increase in detection effort hurts the profit of oil company and the fish biomass instead.

We also study the fish price effects, the increase in the fish price leads to similar results with those in the increase in the detection effort, but only one qualitative difference is that the increase in price results in more profit of the oil company. The results suggest that maintaining a more competitive environment in fish market is better than to increase the detection efforts.

References

Charles, A. T., R. L. Mazany, and M. L. Cross. 1999. The Economics of Illegal Fishing: A Behavioral Model. *Marine Resource Economics* 14: 95-110.

Lindebo, E. 2005. Role of Subsidies in EU Fleet Capacity Management. *Marine Resource Economics* 20: 445-466.

OECD (Organisation for Economic Cooperation and Development). 2006. *Financial Support to Fishery: Implication for Sustainable Development*. OECD, Paris. Available: www.oecd.org/.

Quinn, J., and G. Ruseski. 2001. Effort Subsidies and Entry Deterrence in Transboundry Fisheries. *Natural Resource Modeling* 14(3): 369-389.

Ruseski, G. 1998. International Fish Wars: The Strategic Roles for Fleet Licensing and Effort Subsidies. *Journal of Environmental Economics and Management* 36: 70-88.

Sanchirico, J. N. 2003. Managing Marine Capture Fishery with Incentive Based Price Instrument. *Public Finance and Management* 3(1): 67-93.

Schrank, W. E. and W. R. Keithly, Jr. 1999. The Concept of Subsides. *Marine Resource Economics* 14: 151-164.Sharp, R. and U. R. Sumaila. 2009. Quantification of U.S. Marine Fisheries Subsidies. *North American Journal of Fishery Management* 29: 18-32.

Sumaila, U. R., J. Alder and H. Keith. 2005. Global Scope and Economics of Illegal Fishing. *Marine Policy* 30: 696-703.

Sumaila, U. R., L. The, R. Watson, P. Tyedmers and D. Pauly. 2008. Fuel Price increase, Subsidies, Overcapacity, and Resource Sustainability. *Journal of Marine Science* 65: 832-840.

Tyedmers, P., R. Watson and D. Pauly. 2005. Ambio 34(8): 635-638.

UNEP (United Nations Environmental Program). 2004. *Analyzing the Resource Impact of Fisheries Subsidies: Matrix Approach*. UNEP: New York. Available: www.unep.ch/etb/.

Varian, H. R. 1992. *Microeconomic Analysis*. Norton: New York.

Study on Optimization for Central Financial Special Fund of Environmental Protection

LU Yuantang[1,2], WU Shunze[1], ZHU Jianhua[1]

(1.Chinese Academy for Environmental Planning, Beijing 100012,China;2.Research Institute for Fiscal Science, Ministry of Finance, Beijing 100142)

Abstract: The central special fund of environmental protection is the main channel for the central government to make financial input into the environmental protection in China, which plays an important role in leading the environmental investment of local finance, enterprises and society. Based on the current situation, the article analyzes the scope and emphases supported by various environment special funds. Results show that the special fund lacks the effective integration, tends to be emergency-oriented and needs effective supervision. In light of those problems, the paper probes how to optimize the environmental protection special fund in China and makes some recommendations, such as coordination among various government departments with regard to the use of special funds, establishing a performance-based payment mechanism, founding the state environmental protection investment company as well as strengthening the control of the capital flow, etc.

Key words: environmental protection; special fund; optimum design; performance

The Chinese government has paid high attention to environmental protection and made great efforts in improving investment policies for environmental protection. In recent years the size of environmental protection investment has been increasing year by year due to the enhanced financial input from both government and industrial sector thus providing a strong support for strengthening pollution control and improving environmental quality. The earmarked fund for environmental protection from central finance (hereinafter referred to as central special fund of environmental protection) is the main channel for the central government to make financial input into the environmental protection in China, which plays an important role in leading the environmental investment of local finance, enterprises and society.

1 Central special funds for environmental protection

1.1 Financial input for environmental protection from central finance

There are two sources of central special fund of environmental protection – infrastructure investment administered by the National Development and Reform Commission (NDRC) and central financial special fund administered by the Ministry of Finance (MOF). In 2008, there were 11 special funds under the former with total fund of 11.3 billion RMB yuan (not including the additional fund in the fourth season of the year) and 7 special funds under the latter with total fund of 16.4 billion RMB yuan in which 2.43 billion RMB yuan was budgeted for environmental protection accounting for 2.3% of the central budgeted expenditure.

Of the total amount of central special fund of environmental protection more than half was from the central financial special fund administered by MOF, which is comparatively stable with respect to the size of each special fund. This paper will be focusing on the analysis of various central special funds administered by MOF.

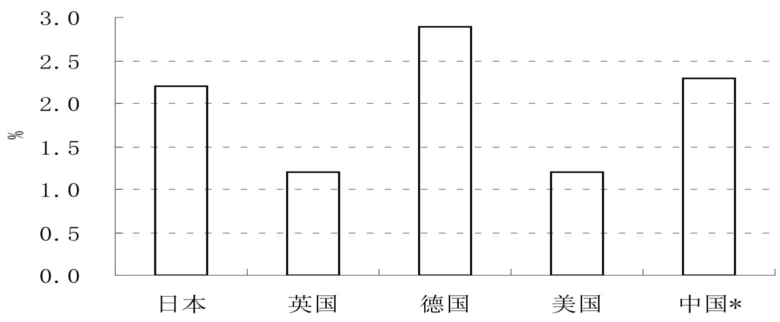


Figure 1 Comparison of environmental expenditure in 2007

* China is based on 2008 data

1.2 Classification of central special fund of environmental protection

The central special fund of environmental protection is the fund earmarked for environmental protection in the central government budget. In general, there are three types of central special fund of environmental protection in terms of the scope supported by the fund.

(1) Comprehensive special fund. It supports to address diverse environmental issues in different regions.

(2) Special fund for specific regions which supports to address environmental issues in one or more regions, e.g. the central special funds for the pollution control in "three rivers and three lakes" regions and in Songhua river basin.

(3) Special fund for specific environmental areas or element, e.g. using money award instead of subsidiary fund in the construction of pipeline network matched with the urban waste water treatment facilities, special fund for protected areas, and central special fund for environmental protection of rural areas.

1.3 Current status of central special fund of environmental protection

The establishment of the central special fund of environmental protection is of great importance in raising fund and increasing the financial input by the central government for environmental protection.

(1) Central special fund of environmental protection

The Ministry of Finance set up the central special fund of environmental protection in 2004. In the "11th Five-Year Plan" period, the fund had supported the capacity-building of environmental monitoring and supervision; water source protection for centralized drinking water supply; regional environmental security; promotion of new techniques and technologies of pollution control; and etc. From 2004 to 2009, a total of 8 billion yuan of the fund had been used in the above-mentioned projects playing an important role in improving the regional environmental quality.

(2) Special fund for emission reduction of key pollutants

The fund set up in 2007 and governed by the《Provisional Regulation on the Administration of the Central Finance Special Fund for Emission Reduction of Key Pollutants》is mainly utilized for supporting the construction of monitoring, indicator, and checking systems of pollution reduction of key pollutants. The allocated fund in 2007, 2008, and 2009 was 1.33, 2.5, and 1.5 billion yuan respectively playing an important role in improving the capacity of environmental monitoring and supervision.

(3) Special fund for water pollution control of "Three Rivers and Three Lakes" and Songhua river basin

To ensure the achievement of emission reduction targets of the "11th Five-Year Plan" period, the central government set up a special fund for the water pollution control of "Three Rivers and Three Lakes" and Songhua river basin in 2007. MOF issued the《Provisional Regulation on the Administration of the Special Fund for the Water Pollution Control of Three Rivers and Three Lakes" and Songhua River Basin》in December 2007. The fund mainly supports the construction projects of waste water treatment and solid waste disposal facilities and their matching pipeline network; industrial waste water complete treatment facility and clean production; regional pollution control; and other water pollution control projects within the planned scope. The transfer payment of the special fund was made from the central government to the provincial government with the latter responsible for the management of specific projects. The total fund transferred in 2009 was 5 billion yuan.

(4) Special fund as money award instead of subsidiary fund to encourage the construction of pipeline network matched with the urban waste water treatment facilities

In 2007, a new means of payment of the special fund was exercised in addition to the subsidy and discounted loan. The projects using discount loan or using money award instead of subsidy are encouraged and prioritized. To support the construction of pipeline network matched with the urban waste water treatment facilities in the central and western areas of China, the central government set up a special fund as money award instead of subsidiary fund to encourage the real increase of urban waste water treatment capacity in those areas and promulgated the《Provisional Regulation on the Administration of the Special Fund as Money Award Instead of Subsidy for the Construction of Pipeline Network of Urban Waste Water Treatment Facilities》in which it is provided that the fund transferred from central government to local government should be strictly earmarked for the construction of pipeline network matched with the urban waste water treatment facilities. The total amount of this fund transferred in 2009 was 10 billion yuan.

(5) Central special fund for rural environmental protection

The central government set up a special fund for rural environmental protection in 2008 using this fund as money award instead of subsidy to encourage and support the integrated environmental management in rural areas and the construction of pilot village. The fund was 500 million yuan in 2008 involving 700 villages. In 2009, the fund was 1billion yuan involving 1400 villages and mainly used to support the protection of drinking water sources, domestic waste water treatment and solid waste disposal, pollution control of animal and poultry production, treatment of contamination caused by rural enterprises which have been out of operation, and pilot ecological conservation projects thus strengthening the integrated environmental management in rural areas and addressing the prominent environmental problems that threaten the health of the public and cause strong complaint, and have adverse impact on the sustainable development[1].

In addition, the central government has set up other special funds such as special fund for nature reserves (protected areas), special fund for pollution control of intensive animal and poultry production, special fund for heavy metal pollution control, financial awards for energy-saving technical renovation and for phasing out out-of-date production capacity, and financial subsidy for the promotion of energy efficient products, etc.

Table 1 Main special funds related to environmental protection

No	Title of the special fund	Emphasis /scope supported	starting year	Responsible department
1	special fund for nature reserves	National protected areas in the central and western areas of China that are of typical ecological characteristics and important scientific value; Well managed national protected areas that can play an exemplary role for other Pas; National PAs that weak in management infrastructure.	2001 年	MOF, former State Environmental Protection Administration
2	special fund for pollution control of intensive animal and poultry production	Pilot projects and technical promotion on pollution control and comprehensive utilization of waste of intensive animal and poultry production enterprises in the central and western areas; regions where the pollution load is heavy due to concentrated and large scale of animal and poultry production; regions with centralized intensive animal and poultry production but without adequate subsidy for pollution control; regions where stakeholders are active in rural environmental protection and strong measures are taken.	2003	MOF, former State Environmental Protection Administration (SEPA)
3	Central special fund for environmental protection	Projects on: environmental monitoring; protection of drinking water source for centralized water supply; regional environmental security; environmental protection action in the construction of new socialist village; promotion and application of new techniques and technologies on pollution control; and other pollution control projects identified by MOF and SEPA	2004	MOF, SEPA
4	Central special fund for emission reduction of key pollutants	Establishing indicator system of emission reduction of key pollutants, and monitoring and performance assessment system to facilitate the government function by the central environmental protection departments. Rewarding enterprises and regions who have made significant achievement in emission reduction	2007	MOF, SEPA
5	Special fund for	Construction of waste water treatment and solid waste disposal facilities and their pipeline network; industrial waste water complete	2007	MOF, SEPA

No	Title of the special fund	Emphasis /scope supported	starting year	Responsible department
	water pollution control of "three rivers and three lakes" and Songhua river basin	treatment facility and clean production; regional pollution control; pollution prevention and control in the drinking water source areas; pollution control of scaled animal and poultry production; integrated treatment of urban water bodies, and other water pollution control projects within the planned scope.		
6	Special fund as money award instead of subsidiary fund to encourage the construction of pipeline network matched with the urban waste water treatment facilities	The construction of pipeline network matched with large-scale waste water treatment facilities in key river basins will be prioritized; emphasis on the construction of pipeline network matched with waste water treatment facilities in water source areas; construction of pipeline network matched with waste water treatment facilities in densely populated urban areas; construction of pipeline network matched with other planned waste water treatment facilities	2007	MOF, Ministry of Construction
7	Central special fund for rural environmental protection	Protection of rural drinking water source; rural domestic waste water treatment and solid waste disposal; pollution control of animal and poultry production; treatment of contamination caused by rural enterprises which have been out of operation; prevention and control of	2008	MOF, Ministry of Environmental Protection (MEP)

No	Title of the special fund	Emphasis /scope supported	starting year	Responsible department
		agricultural non-point source pollution; other integrated environmental management measures that improve rural environmental quality.		
8	Special fund for heavy metal pollution control	Integrated control of pollution sources; addressing the historical legacy of heavy metal pollution; pilot project of contaminated site remediation; and capacity building of heavy metal monitoring.	2009	MOF, MEP
9	Fund for rewarding energy-saving technical renovation	Renovation of coal-fired industrial boilers/kilns; utilization of residue heat and pressure; oil-saving technology and substitute for oil; energy-saving motor system and optimization of energy system. The financial award is aiming at supporting the energy-saving technical renovation of enterprises.	2007	MOF, NDRC
10	Fund for rewarding the phasing out of out-of-date production capacity	13 industries: power, iron making, steel making, electrolytic aluminum, iron alloy, carbide, coke, cement, glass, paper making, alcohol, monosodium glutamate, and citric acid. The fund can only be used for phasing out out-of-date production capacity	2007	MOF
11	Financial subsidy for production of renewed and energy-saving building materials	Discounted loan for expanding production capacity of renewed and energy-saving building materials; money award to the promotion and utilization of renewed and energy-saving building materials; development of relevant technical standards and specifications; relevant administrative expenditure approved by MOF.	2008	MOF
12	Financial subsidy for the promotion of energy efficient products	Promotion of energy efficient products including supervision and examination, standard and labeling, information management, and popularity training, etc.	2009	MOF, NDRC
13	Special fund for renewable energy development	Oil substitute, renewable energy development and utilization in heat supply for buildings, heating and refrigeration, power generation, etc.; using sugar cane, cassava, and sweet sorghum as raw material to produce bio-ethanol ; using oil crops/plants to produce bio-diesel; renewable energy development and utilization for heat supply to buildings, heating and refrigeration; promotion and application of	2006	MOF

No	Title of the special fund	Emphasis /scope supported	starting year	Responsible department
		power generation by wind, solar, and marine energy; other planned renewable energy activities.		

2 Analysis on major problems in central special funds

It is no doubt that the establishment of central special fund of environmental protection has played important role in increasing central government's financial input for environmental protection. However there have been some problems in the operation of the funds such as lack of effective integration, tending to be emergency-oriented, and the low overall effectiveness.

2.1 Lack of integration in environmental investment, without synergy among various funds

At present, each type of special fund has its own focal supporting areas with some overlap between different funds. In general, the size of the funds is comparatively small with each fund established independently and lacking coordination and synergy among various funds. Therefore it is difficult to put together the limited resources for addressing key environmental issues.

2.2 The special fund of environmental protection tends to be emergency-oriented lacking long-term consideration

The existing special funds of environmental protection have been established mainly for dealing with some emergent and significant environmental issues being of apparent ad hoc nature. This is because that China is in a development stage when it is difficult to have the long-term and stable fund sources to guarantee adequate financial input for environmental protection.

2.3 Lacking effective supervision and management, paying much attention to investment and less attention to effectiveness

There is no corresponding mechanism of performance assessment for projects that utilize the environmental protection special fund. Thus the problems emerged in the process of project implementation can't be effectively addressed in time.

3 Recommendation on the optimization of central special funds of environmental protection

Given the current state of the use of central special funds for environmental protection and existing problems in their administration, it is suggested that the central special fund of environmental protection or national environmental protection fund should be established by integrating the existing special funds within the central government budget thus stabilizing the fund source, optimizing the fund payment, mobilizing funds from other sources, strengthening supervision and administration on the fund, and increasing the effectiveness of fund use.

3.1 Integrating special funds of environmental protection to promote synergy

Integrate the existing special funds by establishing a special fund of environmental protection within the central government budget. In terms of environmental elements, the scope of the fund use could be categorized into capacity-building on environmental supervision, water pollution prevention and control, air pollution prevention and control, solid waste pollution prevention and control, and ecological conservation and construction, etc. To follow the existing way of fund administration, the special fund of environmental protection within the central government budget shall be co-administered by MOF and MEP. MOF will be mainly responsible for budgeting and fund administration including the development of annual general budget, budgeting principles and priorities, reviewing project budget and appropriating budgeted fund to implementing organizations of the projects, and supervising the state of fund use and management. MEP will be mainly responsible for the review, supervision and management of the projects which use the special fund, including development of project management measures, organizing the review process on the fund-using project application based on the annual general budget, making suggestion to MOF on the annual budget according to the established budgeting procedures, and, in conjunction with MOF, supervising project implementation and assessing the performance of the projects.

3.2 Establishing national environmental protection fund and founding national environmental protection investment corporation

The national environmental protection fund will be a mixed fund established by government and dominated by government fund for the purposes of controlling pollution, improving environmental quality, promoting socio-economic development, and transformation of economic structure.

The fund will be managed by a fund management agency, i.e. the national environmental protection investment corporation, jointly established by MOF and MEP. The national environmental protection investment corporation will be a non-banking policy financial institution with the corporate status. The Board of Directors (BOD) consisting of representatives from MOF, MEP, and other relevant departments will be established for the corporation. The by-law of the corporation will be developed and the fund custodian bank be identified.

The fund will mainly come from the central government budget including part of pollution fee that has been handed over to state treasury, other special fiscal appropriations, donation of individuals and organization from home and abroad, low interest loan from international financing institutions, other funds approved by the State Council, in which the other special fiscal appropriations can be determined by setting a certain percentage of annual increment of fiscal revenue, or by setting a certain percentage of central tax revenue, such as environment relevant cancellation of export tax refund, vehicle purchasing tax, resource tax, urban maintenance and construction tax, consumption tax, etc. thus stabilizing the fund sources and channels.

The scope of the funs use should be clearly identified. Profit earning by the corporation will be allowed with the condition that certain percentage of the income must be used for environmental pollution control projects. The remaining part of the income can be used for commercial investment, mainly on industrial pollution treatment and other pollution treatment projects that are fund-renewable and profitable.

The way of fund use should be provided. The investment corporation will develop annual plan of fund use; enterprises prepare and submit the application materials; after approval by the Investment Corporation and relevant department the fund can be used for supporting the projects in the form of money award instead of subsidy, low interest loan, and discounted loan, etc.

3.3 Stabilizing fund sources and establishing a performance based mode of fund expenditure

The fund sources include part of pollution fee that has been handed over to state treasury and other budgeted revenue of the central finance. A certain percentage of annual central budget or of the increment of fiscal revenue could be allocated to the special fund of environmental protection, thus ensuring the stable growth of the fund. The way of fund use should be innovated and based on performance. The financial support for pollution control projects could take different mode, e.g. money award instead of subsidy/investment, giving financial subsidy/investment after the completion of the project, in order to maximize the leading role of the special fund of environmental protection in mobilizing the credit capital, social fund and funds from other sources to support environmental protection projects that conform with industry policies, technology policies, and public interests[2].

3.4 Broadening the scope of fun use and strengthening the leading role of the fund

Broadening the scope of fun use or establishing new special fund earmarked to reward, subsidize, or compensate projects that are of obvious environmental and social benefit and could make comparatively major contribute to the achievement of environmental targets. The fund could be used for rewarding enterprises which have made significant achievement in emission reduction and for supporting the development of environmental industry by subsidizing the production and utilization of environmental equipment. The fund could also used for compensating the costs incurred by phasing out enterprises, for supporting the implementation of international environmental conventions and addressing environmental issues of historical legacy, for strengthening the guidance in industrial emission reduction and in industrial restructure.

3.5 Intensifying supervision and management of fund, improving the effectiveness of fund use

It is suggested that the benefit evaluation and investment review should be further strengthened in the effort to improve the benefit of fund use[3]. A dual tracing and benefit-evaluating mechanism being in the charge of both financial departments and competent government agencies of the fund-using organizations should be employed for supervising the use of fund transferred from central finance. The financial departments are mainly responsible for special fund budget, transfer payment, and review of the earmarked fund, etc. The competent government agencies are mainly responsible for tracing project development, project tendering, project implementation, and contracting, etc[4]. They are also responsible for intensifying the supervision over the operation of pollution control facilities and the enforcement of penalty against the law-breaching behaviors in the effort to make the constructed pollution control facilities produce environmental benefits.

References

WEN Wen. Financial special fund boost rural environment renovation [J]. China Environment News.25th May 2009. No.001.

LIU Jinji, SUN Chuanjin, ZHU Hongmei, HU Lili, XU Yunsen. Problems and countermeasures in the use of environmental protection special funds[J]. Environmental Science and Technology. 2008.12.No21.59-60.

HE Qin. Study on some problems for performance audit of financial special fund of environmental protection [J]. Financial Accounting Monthly. 2009. 2.77-79.

JIANG Hongmei. Consideration on strengthening management of financial special fund. Times Finance.2009.No.386.38.

First draft (not yet finish)

Fiscal Policy Responses to Climate Change in Indonesia: Opportunities and Challenges

Authors:
Budy P. Resosudarmo (Australian National University)
and
Abdurohman (Ministry of Finance)

1. Introduction

Most scientists these days agree that climate change is the top environmental issue in this world (Stern, ?). The impacts of this environmental issue thread the sustainability of any living creatures in this world, meanwhile any meaning mitigation action to avoid this catastrophe requires a strong coordination among various nations, and so difficult. Economists argue that climate change is a result of market failure; in which free market mechanism fails to optimally allocate resources due to a negative externality problem.[1] This negative externality is due to the fact that those activities emitting green house gases that cause climate change do not take into account this impact in their cost and benefit accounting; i.e. the cost of this impact does not internalized in the price produced by the activities, and so those activities emit too much green house gases (Krugman, 2010).

A condition of market failure, in most cases, requires the government to intervene the market. One way to do so is through fiscal policies (taxation and expenditure or fiscal stimulus policies). In the environmental context, literature has shown that government intervention through fiscal policy could play an important role in assuring sustainable use of natural resources and safeguarding the environment (Hartwick and Olewiler, 1997). A well-design of tax and royalty systems could ensure that natural resources are not overexploited. Meanwhile, government expenditure such as spending on forestry management agencies directly support optimal management of the resources.

Fiscal policy has also been considered as one of key instruments in both mitigating against and adapting to climate changes. In relation to the mitigation, besides tradable permit systems, carbon taxes are also an alternative option to reduce greenhouse gas emission through pricing policy framework. Either tradable permit system and carbon taxes can provide strong and credible incentive for firms

[1] Externality, in general, refers to situation when the effect of any activity (production or consumption) imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided.

and households to reduce carbon emission and develop alternative technology, as well as to ensure a fair distribution of the associated costs and benefits (Krugman, 2010). Meanwhile, public spending on certain sectors such as coastal protection, health and education can help to reduce country' risk exposure and promote country' resilience.

As an archipelagic country, Indonesia is very vulnerable to the impact of climate change. Prolonged droughts, increased frequency in extreme weather events, and heavy rainfall leading to floods, are a few examples of the impacts of the climate change. In turn, this may lead to harmful effects on agriculture resulting in threats of food security (Jotzo et al, 2009). These threatening impacts coupled with the fact that Indonesia has been named among the three largest greenhouse gases emitters in the world lead Indonesian government to placed climate change issue in high priority. The government has announced a target for Indonesia to reduce emission by 26 percent compared to business as usual by 2020 and by 41 percent if enough international supports are available (DNPI, ?).

To achieve the emission reduction target, fiscal policy clearly has a key role in Indonesia not only through which potential carbon taxes system or other relevant policy schemes can be introduced but also to eliminate environmentally unsustainable biases such as energy subsidy, forestry rent, and profit sharing scheme in mining sector which have distorted price signals leading to over consumption and exploitation.

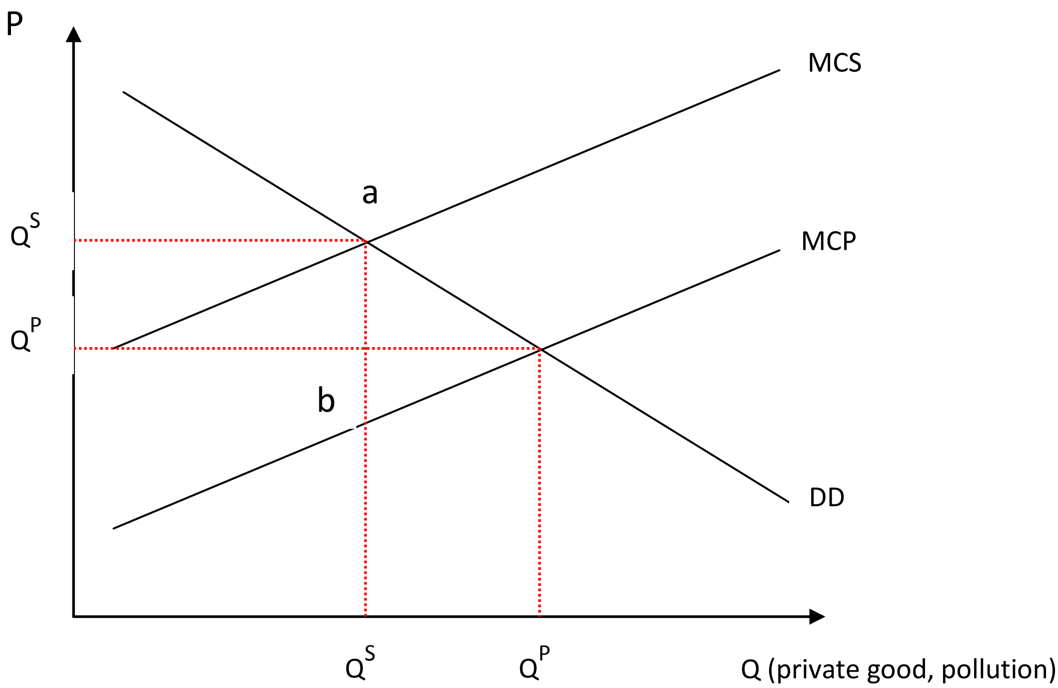
The aim of this paper will first review the existing regime of fiscal policy in Indonesia related to environmental management both from the revenue and expenditure side. On the revenue side, it will describe various green taxes and levies that have been or once implemented in Indonesia. On the expenditure side, broad structures and trends of budget allocated for green activities will be presented. Second, this paper will discuss the structure of CO_2 emissions and challenges for Indonesia in reducing its emissions. Third, this paper will present recent fiscal policies in response to Indonesian commitment to reduce its emission by 2020. This paper will then end up with several final remarks on the opportunities and challenges for Indonesia in achieving its emission reduction target.

2. Green Fiscal Policy: Conceptual framework

Standard literatures on how fiscal policy instruments could contribute to the control of environmental damages usually refers to the comprehensive text book of Boumol and Oates (1988). Negative environmental externality which provides rationale for government intervention is represented with the air pollution case resulted from the smoke from a factory. In a free market situation, the factory will produce too much smoke because it does not take into account the air pollution cost that it imposes on surrounding individuals. As depicted in Figure 1, DD line represents the demand curve of the factory's product (steel). The MCP represents the supply curve (the private marginal cost) for the factory's production (steel). The factory produces two goods; steel and smoke (by product). The higher the price of production the more goods will be supplied. Since the society take into account the air pollution cost, the social marginal cost (MSC) is higher than the MPP.

Figure 1

Pollution and negative externality



Under free market situation, there will be three problems; (i) there is excessive production of pollution-intensive good (steel), (ii) there is too much pollution, and (iii) the price of pollution-intensive good is too low. Therefore, corrective action is needed to force the factory to produce the socially optimal level of pollution.

There are two standard alternative solutions to the above negative externality problem in the standard public finance literature; The Coase Theorem and Pigouvian Tax/Subsidy.

The Coase theorem (Coase, 1960) states that government intervention is not needed to eliminate negative externality of environmental damage. Market will function efficiently as long as property right is well defined. The reason that the market solution produces too much pollution is because the property right of clean air is not well defined. If the factory were to hold the rights, the victim could always pay the factory to reduce the pollution. In contrast, if the victim were to hold the rights, the factory will by the rights pollute. In either case, the bargaining process will continue until the optimal level of pollution is reached. There are two critical assumptions of the Coase theorem. *First*, the bargaining cost is zero. *Second*, there are only a small number of parties so that bargaining is feasible. In the real world, both assumptions is unlikely to happen in most situations underlying the management of environment. However, the Coase theorem suggests the very important role of property rights that need to be considered in designing proper policy interventions.

Another alternative solution of the negative externality is using Pigouvian tax. Pigouvian tax provides the rationale of the role of fiscal policy in environmental management. According to Pigou (1932), the optimal policy intervention, given the nature of competitive market, is to impose tax (effluent fee) on the factory that is equal to the gap between the private and the social curve or the marginal social damage. In the Figure 1, the marginal social damage is equal to "ab". This tax will ensure the factory to produce at the optimal level of pollution. Thus, Pigouvian tax guarantees that the negative externality is fully internalized by the factory.

Theoretically, optimality of the Pigouvian tax will be attained as long as the underlying assumptions are kept to hold. The existence of competitive market and the concave production function are among its critical assumptions. Under monopoly or oligopoly market structure, the polluting industry could shift the Pigouvian tax burden to the consumers without any attempts to reduce pollution. As a consequence, the Pigouvian tax is not effective under monopoly or oligopoly market situation. Practical difficulty in measuring the marginal cost of damage is also another constraint in the application of the Pigouvian tax.

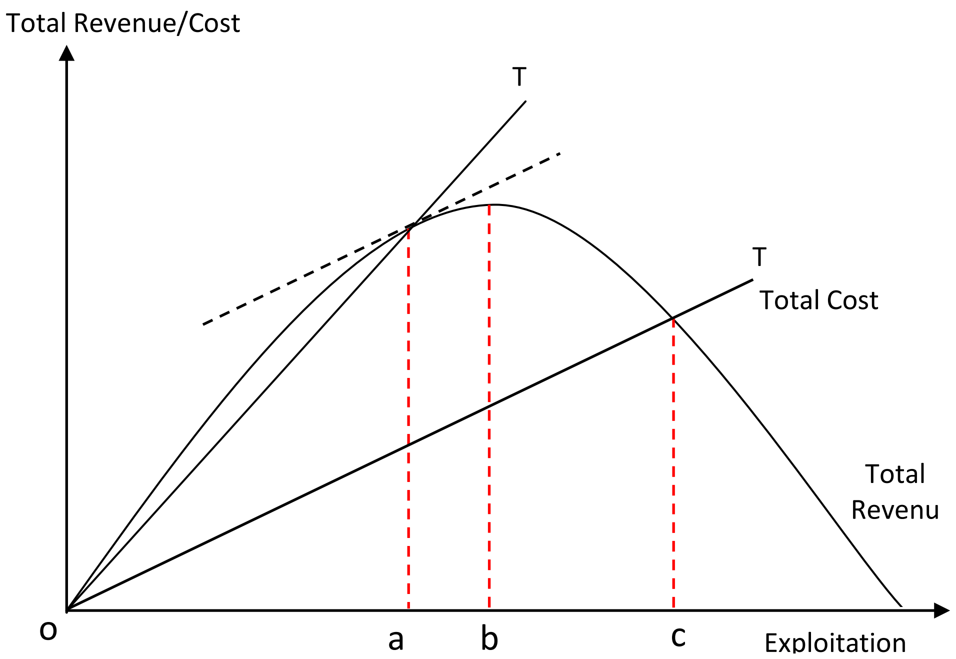
Another fiscal policy measure that can be applied to control pollution is through public investment. According to Boumol and Oates (1988), there are at least two rationales of public investment in this regard. *First*, many environmental services, for example clean air, are pure public goods, and therefore a market based provision is unfeasible. *Second*, an efficient scale of operation of pollution control facilities may require investment levels that much exceed any single polluter's needs due to the lumpiness or indivisibility problem. Thus, the government has to provide services to control pollution.

In the case of natural resource extraction, literature on the resource management distinguishes between a renewable and a non-renewable resource. Each has different policy implications. For renewable resources, the policy challenge is to ensure the maintenance of an efficient sustainable flow while for the non-renewable resource, the policy concern is to ensure a fair inter-generational allocation. Theoretical discussion of natural resource management in this paper will be focused in the case of renewable resources in particular forest and fisheries management.

The main environmental concern regarding a renewable resource such as forest is the risk of extinction, a situation in which the rate of extraction exceeds the rate of regeneration. Related concern is the optimum rate of extraction over time and generation. In the case of forest extraction, market solution will lead to externality problem. Government intervention is then in place to correct the problem usually through property rights assignment (concessionary scheme). There will be two options for rights assignment, open access or a common property. Open access is a situation where there are a large number of concessionaries with no effective quantity restraint on output. Meanwhile, common property refers to the situation where the government give exploitation rights to a limited number of concessionaries. Figure 2 below could be used to illustrate how fiscal policy might help to cope with the renewable resources extraction problem.

Figure 2

Tax and Forest Extraction



By assuming that the price is constant, the shape of the total revenue curve is dictated by the regeneration pattern. At low level of stock, trees regenerate very fast and eventually the stock converges to some maximum level. The cost of forest extraction is assumed to be a monotonic function of the level of effort represented by T^1 and T^2. As shown in Figure 2 above, the level of exploitation effort corresponds to the maximum sustainable yield for forest output will be *ob*. Meanwhile, *oa* is the level of exploitation effort where return is maximized, the efficient level of forest exploitation. In the case of open access, the exploitation level will be at *oc* as profit will be driven to zero. In common property situation, where access (entry) is controlled, the result will be slightly below *oc* but still inefficient.

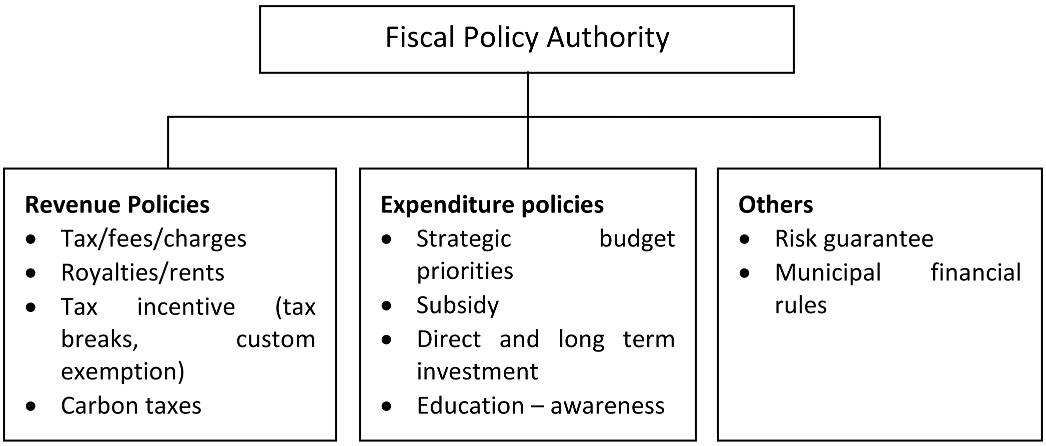
How can fiscal policy help in this case? There are at least two possible interventions. First, government might determine the optimal level of extraction and license accordingly. However, strict monitoring is needed to ensure this policy. Second option is to impose tax (similar to Pigouvian tax) such that the efficient level of forest extraction is attained. In Figure 2 above, the tax will shift the cost curve upward pivotally from T^1 to T^2 so that the force the extraction level at the efficient level (*oa*).

The above two theoretical illustrations show us how important fiscal policy is to correct market failures which lead to environmental damages either in the form of pollution or unsustainable natural resource extraction. Therefore, attention to design greener fiscal policy is increasing recently both in developed and developing countries. Well design green fiscal policy helps to protect environment as well as to enhance sustainable natural resource use. In the most current context is to respond to the climate change challenges.

Indeed, the range of fiscal measures to respond to the challenge of climate change is wide. Despite of the tax and expenditure instruments, other fiscal measures can have directly or indirectly impacts on the environment. Figure 3 below summarizes possible fiscal measures which directly or indirectly influence the environmental outcome.

Figure 3

Green Fiscal Policy Instruments



Source: adapted from COP 13, Bali (2007)

Tax and royalty system is key to ensure that a country receive a proper share of the rents earned by the extraction of natural resources to ensure that those resources are not overexploited. For many developing countries, rents from mining, forestry, or fisheries can have important source of government revenue. However, tax and royalty regime should be designed such that efficient sustainable resources extraction is attained at the same time.

Taxes can also be used to ensure that prices reflect the full costs of producing goods and services. This type of pricing is most conducive for sustainable growth in the long run. For example, the price charged for fuel oil products should reflect not only the cost of purchasing or selling them in the international market but also the air pollution caused from their usage. Tax incentives, for instance tax break and exemptions, are another option of fiscal measures to support more sustainable development programs. Tax break and import duties exemptions are among facilities that frequently used to attract investment on clean energy development such geothermal, wind power and bio-fuel.

In the expenditure side, public spending on environmental management agencies will help to prevent environmental degradation and support more sustainable natural resource use. However, other kinds of spending may advertently increase environmental externalities by pursuing objectives that could be better achieved by less damaging instrument. For instance, energy subsidies are intentionally to serve distributional goals but generate adverse environmental effects that could be avoided. The underlying equity objectives could still be met by eliminating such subsidies and spending the fund saved on food, basic health or education.

Another fiscal instrument that could be used to influence the environmental is risk guarantee. This particular type of scheme is usually applied to attract private sector to invest in green project such as renewable energy generation, for instance geothermal power generation. Since the uncertainty and the risk of exploration of geothermal are high, the government provide risk guarantee. In country with decentralized fiscal policy, municipal financial arrangement could also be used to address environmental objective through earmarking on some local government spending.

3. Key Green Fiscal Policies in Indonesia

This section will not be able to cover all fiscal policies in Indonesia, however, it will cover the key policies.

3.1. Ministry of the Environment

In Indonesia, concern for environmental problems has been demonstrated since the late 1978 when President Soeharto appointed Emil Salim as the first Minister concerning the environment.[2] Since then, fiscal budget has been allocated to this environmental ministry to design regulations and programs managing the country's environment. The first law concerning the environment produced was the Law No. 4/1982 on Basic Provisions of Environmental Management which was enacted in

[2] At that time the name of this agency was the State Ministry of Development Supervision and the Environment. In 1983, it was renamed into the State Ministry of Population and the Environment. In 1993, it became the State Ministry of the Environment. In this paper, we will call all of them as the Ministry of the Environment.

1982 (Koesnadi, 1989). After this law, various laws and regulations have been produced.

Figure 4 shows the size of budget allocated to the Ministry of the Environment, this allocation is certainly one of the key green fiscal policy in this country. With this budget, the Ministry is able to develop various programs to manage the environment. Examples of program have been developed are as follows.

<<Put Figure 4 over here>>

The first serious attempt to control pollution was made in 1989 when then the Ministry of the Environment, through the Government Regulation No. 29/1986, started to require any firm and other development program to submit a report on the expected impact of its activities on the environment, its proposed actions to avoid or minimise this impact, and what environmental impact monitoring activities it will undertake. The report is called an environmental impact assessment (Analisa Mengenai Dampak Lingkungan or AMDAL). The report is assessed by whichever government agency has the authority to permit the activity. If the project is expected to have a serious environmental impact, the report needs to be assessed by an inter-sectoral team involving the Ministry of the Environment.

The Clean River Program, also known as PROKASIH (Program Kali Bersih), was started in 1989 in response to the declining quality of rivers in Jakarta. It is based on a consensual approach to control wastewater effluents by targeting selected industrial polluters in priority river basins. The goal is to improve river quality by setting a specified standard for the river water based on some parameters — usually biochemical oxygen demand (BOD) and total suspended solids (TSS) — established by government (Resosudarmo et al., 1997; ADB, 1997). This program also attempts to strengthen human and institutional abilities in the management of river water quality and of riverbanks (Resosudarmo, 2003).

In June 1990, through the Presidential Decree No. 23, a national environmental impact management agency (Badan Pengendalian Dampak Lingkungan or BAPEDAL) was established (Hardjono, 1994). The main task of this agency is to implement various programs developed by the Ministry of the Environment.

The PROPER program was started in June 1995 as an alternative environmental policy developed by the Ministry of the Environment. PROPER is basically an environmental rating program that acts as a simple environmental certification. Its main objectives are to increase compliance with environmental regulations, promote adoption of clean technologies, create incentives for polluters to strengthen their in-house environmental capabilities, and prepare companies in Indonesia for International Standards Organization (ISO) 14001 certification (Wheeler and Afsah, 1996; ADB, 1997).

Implementation of this program was conducted by BAPEDAL. Each year BAPEDAL evaluated companies participating in this program regarding their environmental abatement activities. Based on their success in reducing waste discharges, mainly water effluents — hence the program was also called PROPER PROKASIH — these companies were given one of five different colour scores (ADB, 1997). The results were published in newspapers and other media to make them known publicly.

In 2002 the Ministry of the Environment developed a new PROPER program with a more comprehensive goal. The goal is multi media management, where the program is targeted not only to control water, air, and toxic waste discharges, but also as a part of environmental impact assessment (AMDAL). It is also equipped with new regulations such as Government Regulation No. 27/1999 on environmental impact assessment (AMDAL), Regulation No. 18/1999 on toxic waste management, Regulation No. 82/2001 on air and water pollution, Ministerial Decree No. 113/2003 on waste water discharge and Ministerial Decree No. 129/2003 on emission (Ardiputra, 2004).

Besides PROPER, limited monitoring activities are conducted for hazardous waste disposal. Only a small number of industries dispose of their hazardous wastes at the existing treatment facilities. On the other hand, the number of hazardous waste treatment plants and the type of facility available in a treatment plant are limited. In fact, the Cileungsi Hazardous Waste Treatment Plant near Jakarta (operational in 1994) is the only treatment facility capable of processing the waste and providing a secure storage area and a lined landfill for the disposal of stabilized and low level toxins (World Bank, 2003).

3.2. Taxes and charges

Several user charges have been levied throughout Indonesia. These are particularly related to municipal services such as drinking water, wastewater treatment, solid waste collection and disposal, and to road/transportation services (ADB, 1997; Rock, 2000). Several examples related to industrial pollutants are as follows.

For water management, in most provinces a surface or raw water use licence is required for withdrawing surface water, with the license fee starting at US$43 in 1996. For six main classes of customers, a volume based fee is added, ranging from zero for households to Rp 150/m^3 for industrial users (ADB, 1997; Rock, 2000). These prices are considered low, particularly for industrial users, and hence it is expected that these prices do not really affect people and industrial behaviours in using water.

Furthermore, there are around 300 PDAMs (state-owned municipal water companies) providing access to treated pipe water for around 36 percent of the urban population throughout the country, with fees averaging Rp 350–2,000 per m^3. These prices are considered too low, and so many of these PDAMs are in financial difficulty. In 2004, the government enacted a new law allowing private enterprises to manage the water supply in various regions across the country (PERPAMSI, 2004).

For sewage disposal, in 1989 the Ministry of Public Works decided to use a levy for sewage disposal. This levy covers five categories of users and in 1997 was set according to the floor space of a building, office or house. The rate in 1990 was from Rp 28 per m^2 for households to Rp 182 per m^2 for commercial high rise buildings (ADB, 1997; Rock, 2000). Local governments are responsible for the management of sewage disposal collection, which is generally conducted either by contractors or residents themselves. Only a miniscule portion of the solid waste is recycled and most of it is conducted by the informal private sector such as scavengers in many large cities in Indonesia (World Bank, 2003).

The user charge was less effective in managing solid wastes than in the case of water management. The main reason was that the agency that managed the solid waste did not collect the charge. The management of solid wastes was funded through a Presidential Instruction Decree (Inpres) by provincial governments, while local/district financial offices or *Dinas Pendapatan Daerah* (Dispenda) collected the fees (Rock, 2000). There was not much collaboration between Dispenda and the provincial government. Due to the lack of an effective user charge system, solid waste collection in urban areas ranges from 40 to 85 percent of total wastes, including the share attributable to scavengers (ADB, 1997; Rock, 2000). In several areas though, due to financial strain, the government privatised some collection services and most of these were considered to be more successful (Rock, 2000).

Since the 1980s, a fuel tax of as much as 5 percent was introduced in Indonesia. The main goal, though, was to raise the revenue of local governments. Of the total fuel tax revenue, 10 per cent is for the central government, and the rest is distributed to provincial, district and municipal governments. Since 1997, however, the government has subsidised domestic fuel prices by much more than 5 percent, so this fuel tax has not been effective in controlling its use.

3.3. Subsidy

3.4. Public expenditure

3.5. Decentralized fund on environment

4. Greenhouse Gas Emission in Indonesia

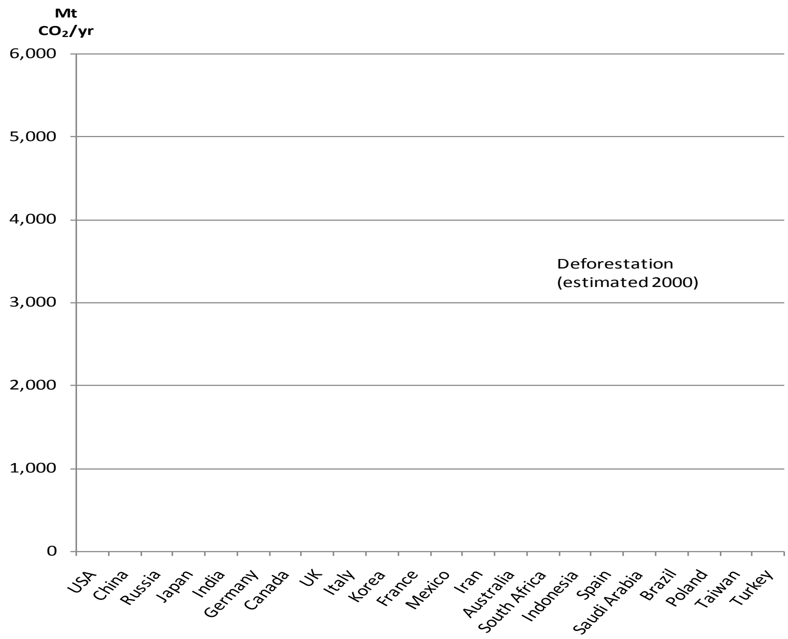
During the 1970s, 1980s, and 1990s, the Indonesian economy, measured by its gross domestic product (GDP), grew with an average annual rate above 7 percent, which was relatively fast compared to many other countries. The country's economy had also been transformed from a more agriculturally dominated economy to a more industrially dominated one (Hill, 2000; Resosudarmo and Kuncoro, 2006;

Resosudarmo and Vidyattama, 2007). This fast growing economy, with a significant transformation toward industrialized activities, increased the amount of CO_2 emitted from fossil fuel combustions.[3] Consequently, there are three important facts related to Indonesia's CO_2 emission from fossil fuel combustions.

First, Indonesia is one of the highest CO_2 emitter countries in the world (IEA, 2006). Since 2004, Indonesia is among the top 25 CO_2 emitters, or ranked 16th when counting EU as one country, due to fossil fuel combustions (Figure 5). The exact rank is somewhat sensitive; i.e. could easily change, as there are many countries that have only a slightly lower level of emissions than Indonesia. If CO_2 emission due to deforestation and land use change are included, Indonesia then becomes among the top 3-5 emitters (Sari et al., 2007). It is important to note, however, that there are serious questions on the reliability of CO_2 emission data from deforestation and land use change.

Figure 5

Top 25 Global CO_2 Emitters in 2004



Source:

- International Energy Agency (2007) [http://www.iea.org/] (fossil fuel emission)
- World Resource Institute (2007) [http://www.wri.org/#] (deforestation emission)

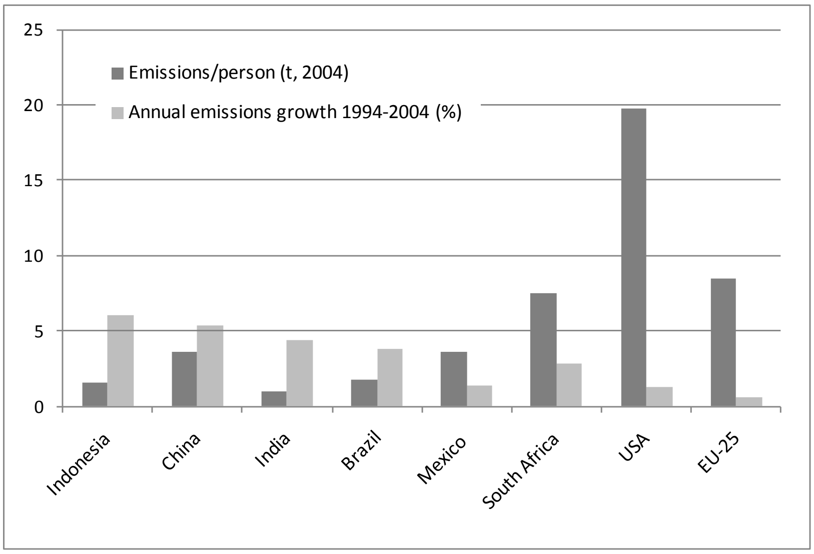
Second, in terms of CO_2 emission per capita from fossil fuel combustions, Indonesia's emission per capita is still low in comparison with other countries (IEA,

[3] At least for Indonesia, CO_2 is the most important green house gases.

2006); however, as it can be seen in Figure 6, it is growing relatively fast. From 1994 till 2004, Indonesia's CO_2 emission per capita from fossil fuel combustions grew faster than China's and India's.

Figure 6

Fossil Fuel CO_2 Emissions per Capita and Their Growth Rates

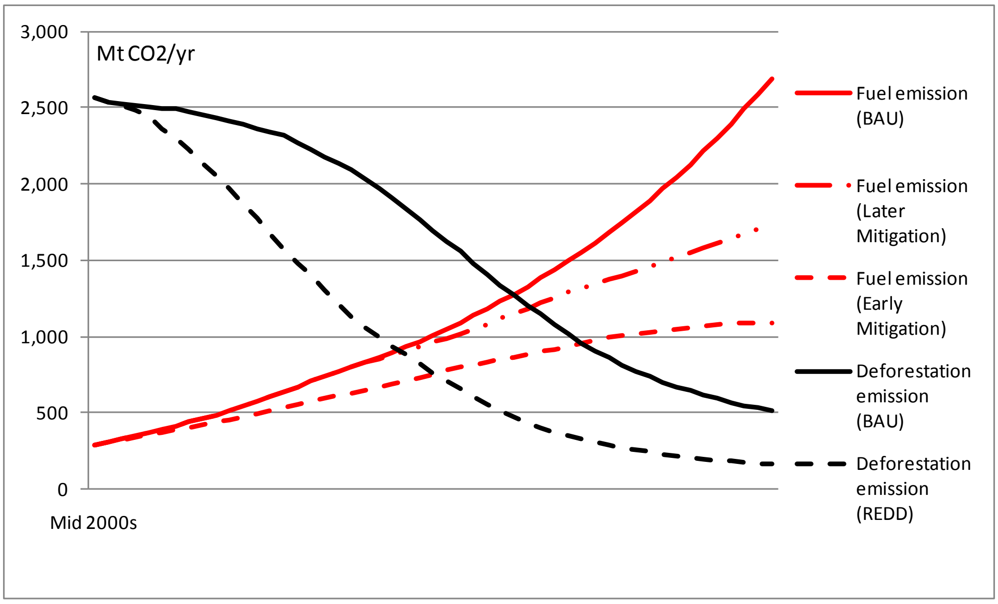


Source: International Energy Agency (2007) [http://www.iea.org/]

Third, in the long run, CO_2 emission from fossil fuel combustions will most likely be much more important than that caused by deforestation and land use change. Emissions from deforestation and land use are now much greater than that from fossil fuel combustions, but in the future there should be a tendency for slower deforestation emission as the rate of deforestation will be slower due to decreasing available forest areas. Meanwhile, energy use and fossil fuel emissions will keep growing as GDP grows unless mitigating actions are taken. This situation can be illustrated by Figure 7. Important to note is that Figure 7 does not make any judgements about actual future growth/reduction rates and cross-over date between deforestation and fossil fuel emissions. It does, however, illustrate the most likely trajectories.

Figure 7

Emissions from Deforestation and Fossil Fuel



As a consequence of the three facts related to CO_2 emission from fossil fuel combustions mentioned above, in order to keep a low-carbon growth in Indonesia, a two-pronged strategy must be simultaneously implemented: reduce deforestation and bring fossil fuel onto a lower trajectory. Starting soon will make a big difference over time. With regards to fossil fuel combustions, it is crucial to bear in mind of the fact that investments in the energy sector have long lifetimes, often more than 35 years. Investments taken now are locked in a carbon emission trajectory for a long time (IEA, 2003).

5. Fiscal Policy Response to Climate Change in Indonesia

6. Final Remark

On the preference constraint for sustainable development to be optimal*

Ken-Ichi Akao

School of Social Sciences, Waseda University, Japan

akao@waseda.jp

February 22, 2010

* I thank Partha Dasgupta, Kazuhiro Ueta, Akira Maeda, Shunsuke Managi and other participants of the Kyoto Seminar on Sustainable Economic Development (2/16/2010, Kyoto University) for their helpful comments.

On the preference constraint for sustainable development to be optimal

Abstract: This paper defines a sustainable development path as a balanced growth path with environmental conservation. In the framework of endogenous growth theory, it is known that a sustainable development path is optimal only if the following three conditions are satisfied: 1) the engine of economic growth is clean; 2) the assimilation capacity of the environment is high enough to endure the increasing environmental load with economic growth; and 3) the population is not so greedy in the sense that the elasticity of the marginal utility of consumption is greater than or equal to one. While all of these three conditions are intuitively plausible, there are distinctions between the first two and the last one: the former can be obtained by our endeavors, whereas the latter concerns preference that is endowed rather than obtained. We show that this preference constraint can be relaxed if the production technology satisfies the condition that the elasticity of transformation to the production factor and the environmental service, after appropriate monotone transformation, is greater than one.

Keywords: Sustainable development path, Endogenous growth model, Elasticity of the marginal utility, Elasticity of transformation

Journal of Economic Literature Classification Numbers: O11; O13; Q20

1 Introduction

While there are several definitions of sustainable development (see, for example, Pearce et al., 1989, pp.175-183), it is unanimously agreed that when economic growth and environmental conservation are continuous, it is sustainable development. In order to address the possibility and the optimality of such sustainable development, endogenous growth theory provides a suitable framework, because whether or not economic growth is sustainable is the central question of the theory. In fact, there are a number of studies that incorporate environmental factors into an endogenous growth model (see the surveys by Smulders, 1999). Those studies typically look at an optimal steady state where each economic variable has a constant growth rate and examine the conditions under which the economy has both economic growth and environmental conservation.

The important result is obtained by Aghion and Howitt (1998, Chapter 5). They show that sustainable development is optimal only if the following three conditions are satisfied: 1) there is an industrial sector that is environmentally friendly and free from decreasing returns to scale, i.e., the growth engine of the economy is clean; 2) the assimilation capacity of the environment is high enough to endure the increasing environmental load with economic growth; and 3) the population is not so greedy in the sense that the elasticity of the marginal utility of consumption is greater than or equal to unity. The same results are obtained in a more comprehensive model that incorporates pollution not only from production but also from consumption and takes account of recycling and its endogenous technological progress (Akao and Managi, 2007).

While all of these three conditions are intuitively plausible, there are distinctions between the first two and the last one: the former two are necessary conditions for sustainable development to be feasible, but the latter is not. Furthermore, and more importantly, the former can be obtained by our endeavors, whereas the latter concerns preference that is endowed, rather than obtained. If the condition on the preference is valid, sustainable development may never be a social goal common to all humankind, because our society consists of various people whose elasticities of the marginal utility of consumption may vary. Then, an interesting question is how the preference constraint can be relaxed. We investigate the possibility.

There is an immediate and affirmative answer to the question, if we assume that the consumption c and the environmental service (or the pollution abatement service) x are perfect substitutes such as in the following AK model:

$$\max \int_0^\infty u(c,x)e^{-\rho t}dt \text{ subject to } \dot{K} = AK - (\psi x + c), \tag{1.1}$$

where A and ψ are positive constants. Since this assumption seems less realistic or less appealing, we do not consider this sort of trivial model.

This paper confines its attention to an optimal steady state. We assume the utility and production functions whose elasticities of the first derivatives are constant. This class of functions contains the CIES utility function and the Cobb–Douglas production function which are quite often used in the literature on endogenous growth. Our results are: 1) the preference constraint can be relaxed under a certain condition on the production function; and 2) if the production function is of Cobb–Douglas type, then the preference constraint cannot be relaxed. The second result is confirmed with a flow pollution model, a stock pollution model, and a recursive utility model with flow pollution. The paper is organized as follows: Section 2 uses a simple exogenous growth model with flow pollution and shows the above two results within a framework of exogenous technological change. Section 3 modifies the model to a stock pollution model and to a recursive utility model to examine whether the previous results change. In Section 4, we consider an endogenous growth model with flow pollution to verify the first result above. Also, the section gives the economic interpretation of the condition on the production function: the elasticity of transformation to the production factor and the environmental service (or the pollution abatement service), after an appropriate monotone transformation, is greater than one.

2 Constant elasticity model

This section uses the following simple model:

$$\max_{c(t)\geq 0, x(t)\geq 0} \int_0^{\infty} u\left(c(t), x(t)\right) e^{-\rho t} dt \tag{2.1}$$

$$\text{subject to } \dot{K}(t) = e^{gt} f\left(K(t), x(t)\right) - c(t),\ \ K(t) \geq 0\ K(0) = K > 0 \text{ given.} \tag{2.2}$$

We make the following assumption:

Assumption 1: The utility function $u : \mathbb{R}_+^2 \to \mathbb{R} \cup \{-\infty\}$ and the production function $f : \mathbb{R}_+^2 \to \mathbb{R}_+$ are twice continuously differentiable and concave. They satisfy $u_c > 0$ and $f_K > 0$.

x is either of the pollution flow or the environmental service. In the former case, $u_x < 0$ and $f_x > 0$, whereas in the latter case, $u_x > 0$ and $f_x < 0$. This section assumes, for simplicity, that the technological progress is exogenous with the growth rate $g > 0$. Denote the growth rates of the time variables by:

$$g_c = \frac{\dot{c}}{c}; g_K = \frac{\dot{K}}{K};\ \text{and } g_x = \frac{\dot{x}}{x}. \tag{2.3}$$

We denote the elasticities of the first derivatives of the utility and the production functions by:

$$
\begin{aligned}
\sigma_{cc}^{u} = \frac{-cu_{cc}}{u_c}; \sigma_{cx}^{u} = \frac{xu_{cx}}{u_c}; \sigma_{xc}^{u} = \frac{cu_{xc}}{u_x}; \sigma_{xx}^{u} = \frac{-xu_{xx}}{u_x}; \\
\sigma_{KK}^{f} = \frac{-Kf_{KK}}{f_K}; \sigma_{Kx}^{f} = \frac{xf_{Kx}}{f_K}; \sigma_{xK}^{f} = \frac{Kf_{xK}}{f_x}; \sigma_{xx}^{f} = \frac{-xf_{xx}}{f_x};
\end{aligned}
\tag{2.4}
$$

Assume:

Assumption 2: The elasticities in (2.4) are constant.

As seen later, the functions satisfying this assumption include the CIES utility function and the Cobb–Douglas production function, and this assumption is satisfied with most of endogenous growth models. We define a sustainable development path as:

Definition: A path is a sustainable development path if $g_c > 0$ and $g_x \leq 0$ in the case that x is pollution flow ($g_x \geq 0$ in the case that x is an environmental service), and all growth rates are constant.

Unless otherwise noted, we suppose that the growth rates are constant (i.e., the economy is in a steady state). As is well known, when the state equation is given as in (2.2), a steady state is a balanced growth path: $g_c = g_K = g_y$, where $y = e^{gt}f(K, x)$. This relationship is verified from the following fact:

Lemma 2.1 *Let $z_i \neq 0$ and g_i $(i = 1, 2, 3)$ be real numbers. If $z_1 e^{g_1 t} = z_2 e^{g_2 t} + z_3 e^{g_3 t}$, then $g_1 = g_2 = g_3$.*

Proof. The condition is rewritten as:

$$
z_1 = z_2 e^{(g_2 - g_1)t} + z_3 e^{(g_3 - g_1)t}. \tag{2.5}
$$

(2.5) holds only if $g_2 - g_1 = g_3 - g_1$, i.e., $g_2 = g_3$. Then, (2.5) is rewritten as $z_1 = (z_2 + z_3)\, e^{(g_3 - g_1)t}$,which holds only if $g_1 = g_3$. ■

Remark: $g_c = g_K = g_y$ is obtained by seeing $g_K = \dot{K}/K = y/K - c/K$ as $g_K e^{g_1 t} = (y(0)/K(0))e^{g_2 t} - (c(0)/K(0))e^{g_3 t}$ with $g_1 = 0, g_2 = g_y - g_K$, and $g_3 = g_c - g_K$.

The Hamiltonian associated with the problem (2.1) is given by:

$$H(c, x, K, \lambda) = u(c, x) + \lambda[e^{gt} f(K, x) - c], \tag{2.6}$$

where λ is the costate variable. The first order conditions for an interior solution of the problem (2.1) are:

$$\text{(a) } u_c - \lambda = 0; \text{ (b) } u_x + \lambda e^{gt} f_x = 0; \text{ and (c) } \dot{\lambda} = \rho\lambda - \lambda e^{gt} f_K. \tag{2.7}$$

From (2.7 a),

$$g_\lambda = -\sigma^u_{cc} g_c + \sigma^u_{cx} g_x. \tag{2.8}$$

From (2.7 b),

$$g_\lambda = \sigma^u_{xc} g_c - \sigma^u_{xx} g_x - \sigma^f_{xK} g_K + \sigma^f_{xx} g_x - g. \tag{2.9}$$

Since g_λ is constant on a balanced growth path, the first order condition (2.7 c) implies:

$$g - \sigma^f_{KK} g_K + \sigma^f_{Kx} g_x = 0. \tag{2.10}$$

Combine (2.8), (2.9) and (2.10) to obtain:

$$\left(\sigma^u_{xx} + \sigma^u_{cx} - \sigma^f_{xx} - \sigma^f_{Kx}\right) g_x = \left(\sigma^u_{cc} + \sigma^u_{xc} - \sigma^f_{xK} - \sigma^f_{KK}\right) g_c. \tag{2.11}$$

Equation (2.11) gives the relationship between economic growth and the environment. In the case that x is pollution flow, sustainable development ($g_c > 0$ and $g_x \leq 0$) is optimal only if:

$$\left(\sigma^u_{xx} + \sigma^u_{cx} - \sigma^f_{xx} - \sigma^f_{Kx}\right)\left(\sigma^u_{cc} + \sigma^u_{xc} - \sigma^f_{xK} - \sigma^f_{KK}\right) \leq 0. \tag{2.12}$$

Similarly, if x is an environmental service, then sustainable development defined by $g_c > 0$ and $g_x \geq 0$ is optimal only if:

$$\left(\sigma^u_{xx} + \sigma^u_{cx} - \sigma^f_{xx} - \sigma^f_{Kx}\right)\left(\sigma^u_{cc} + \sigma^u_{xc} - \sigma^f_{xK} - \sigma^f_{KK}\right) \geq 0. \tag{2.13}$$

Therefore, the optimality of sustainable development depends not only on the preference parameters but also on the technology parameters. These parameters are subject to some constraints. Such constraints, in turn, limit the functional forms of the constant elasticity functions. The economic assumptions such as monotonicity and concavity further specify the functions and limit the combinations of the functional forms of the utility and the production functions.

Lemma 2.2 *Under Assumptions 1 and 2, (i) either of the following holds: (a)* $\sigma^i_{xj} = \sigma^i_{jx} = 0$ *or (b)* $\sigma^i_{jj} + \sigma^i_{xj} = \sigma^i_{xx} + \sigma^i_{jx} = 1$*, where* $i = u, f$ *and* $j = c$ (K) *if* $i = u$ (f)*. (ii) Corresponding to each case, the utility and the production functions take the forms:*

$$u(c,x) = \text{ (a) } \frac{c^{1-\sigma^u_{cc}} - 1}{1-\sigma^u_{cc}} + \gamma\frac{x^{1-\sigma^u_{xx}} - 1}{1-\sigma^u_{xx}} \text{ or (b) } \frac{\left(cx^{\phi}\right)^{1-\sigma^u_{cc}}}{1-\sigma^u_{cc}}, \tag{2.14}$$

$$f(K,x) = \text{ (a) } AK^{1-\sigma^f_{KK}} - Bx^{1-\sigma^f_{xx}} \text{ or (b) } AK^{1-\sigma^f_{KK}}x^{1-\sigma^f_{xx}}, \tag{2.15}$$

respectively, where $\phi = (1-\sigma^u_{xx})/(1-\sigma^u_{cc})$*. (iii) The production function (2.15 b) is available only in the case of* $f_x > 0$*. If* $\sigma^u_{cc} \in (0,1)$*, then the utility function (2.14 b) is available only in the case of*

$u_x > 0$.

Proof. Consider first the utility function. Since $\partial \ln u_c/\partial c = -\sigma^u_{cc}/c$ and $\partial \ln u_c/\partial x = \sigma^u_{cx}/c$, u_c is solved as:

$$u_c = \left(c^{-\sigma^u_{cc}} x^{\sigma^u_{cx}}\right) \left(\bar{c}^{-\sigma^u_{cc}} \bar{x}^{\sigma^u_{cx}}\right)^{-1} u_c(\bar{c}, \bar{x}),$$

where $(\bar{c}, \bar{x}) > 0$ is the reference point chosen arbitrarily. Similarly, we obtain:

$$u_x = \left(c^{\sigma^u_{xc}} x^{-\sigma^u_{xx}}\right) \left(\bar{c}^{\sigma^u_{xc}} \bar{x}^{-\sigma^u_{xx}}\right)^{-1} u_x(\bar{c}, \bar{x}).$$

In order for these partial differential equations to have a solution, the integrability condition must be satisfied:

$$\begin{aligned} u_{cx} &= \sigma^u_{cx} \left(c^{-\sigma^u_{cc}} x^{\sigma^u_{cx}-1}\right) \left(\bar{c}^{-\sigma^u_{cc}} \bar{x}^{\sigma^u_{cx}}\right)^{-1} u_c(\bar{c}, \bar{x}) \\ &= \sigma^u_{xc} \left(c^{\sigma^u_{xc}-1} x^{-\sigma^u_{xx}}\right) \left(\bar{c}^{\sigma^u_{xc}} \bar{x}^{-\sigma^u_{xx}}\right)^{-1} u_x(\bar{c}, \bar{x}) = u_{xc}. \end{aligned} \tag{2.16}$$

There are two cases for (2.16) to hold: (a) $\sigma^u_{cx} = \sigma^u_{xc} = 0$ and

$$\text{(b) } \sigma^u_{cc} + \sigma^u_{xc} = \sigma^u_{xx} + \sigma^u_{cx} = 1 \text{ and } \frac{\sigma^u_{cx} u_c(\bar{c}, \bar{x})\bar{c}}{\sigma^u_{xc} u_x(\bar{c}, \bar{x})\bar{x}} = 1.$$

For the case (a), the solution takes the form:

$$u(c, x) = \left(\frac{c^{1-\sigma^u_{cc}} - 1}{1 - \sigma^u_{cc}}\right) + \gamma \left(\frac{x^{1-\sigma^u_{xx}} - 1}{1 - \sigma^u_{xx}}\right). \tag{2.17}$$

In order to satisfy the properties of the utility function such as concavity, it must hold that $\sigma^u_{cc} > 0$. Also, if $u_x > 0$, then $\gamma > 0$ and $\sigma^u_{xx} > 0$, while if $u_x < 0$, then $\gamma < 0$ and $\sigma^u_{xx} < 0$. For the case (b), the solution takes the form:

$$u(c,x) = A\left(\frac{c^{1-\sigma^u_{cc}}}{1-\sigma^u_{cc}}\right)\left(\frac{x^{1-\sigma^u_{xx}}}{1-\sigma^u_{xx}}\right). \tag{2.18}$$

$u_c > 0$ implies $A/(1-\sigma^u_{xx}) > 0$. If $u_x > 0$, then $A/(1-\sigma^u_{cc}) > 0$ and thus $(1-\sigma^u_{xx})/(1-\sigma^u_{cc}) > 0$. Similarly, we have $(1-\sigma^u_{xx})/(1-\sigma^u_{cc}) < 0$ in the case of $u_x < 0$. Letting $\phi = (1-\sigma^u_{xx})/(1-\sigma^u_{cc})$ and setting $A/(1-\sigma^u_{xx}) = 1$, (2.18) becomes:

$$u(c,x) = \left(\frac{cx^{\phi}}{1-\sigma^u_{cc}}\right)^{1-\sigma^u_{cc}}, \tag{2.19}$$

with $\phi > (<) 0$ if $u_x > (<) 0$. The concavity of u requires:

$$\phi(\phi(1-\sigma^u_{cc}) - 1) \leq 0 \text{ and } \phi(\phi(1-\sigma^u_{cc}) - \sigma^u_{cc}) \leq 0.$$

If $\sigma^u_{cc} < 1$, these inequalities hold only if $\phi \in (0, \sigma^u_{cc}/(1-\sigma^u_{cc})]$, i.e., the case of $u_x > 0$.

Now, we turn to the production function. The production function takes a form like (2.17) or (2.18), but needs to satisfy the nonnegativity condition $f \geq 0$. Therefore, for the case of (a), it is written as:

$$f(K,x) = AK^{1-\sigma^f_{KK}} - Bx^{1-\sigma^f_{xx}}, \quad 0 < \sigma^f_{KK} < 1,\ A > 0. \tag{2.20}$$

In order to satisfy the concavity, the parameters satisfy $0 < \sigma^f_{xx}$ and $B(1-\sigma^f_{xx}) < 0$ if $f_x > 0$, while $\sigma^f_{xx} < 0$ and $B(1-\sigma^f_{xx}) > 0$ if $f_x < 0$. For the case (b), the production function takes the form of:

$$f(K,x) = AK^{1-\sigma^f_{KK}}x^{1-\sigma^f_{xx}}, \quad 1 \leq \sigma^f_{KK} + \sigma^f_{xx},\ \sigma^f_{KK}, \sigma^f_{xx} < 1,\ A > 0. \tag{2.21}$$

Note that the concavity requirement excludes the case of $f_x < 0$. ■

The following is the key result of this paper.

Proposition 2.1 *Under Assumptions 1 and 2, if* $\sigma_{cc}^{u} < 1$ *and if an optimal sustainable development path exists, then the production function should take the form of (2.15 a) in Lemma 2.2.*

Proof. We show that $\sigma_{cc}^{u} < 1$ is not compatible with the production function (2.15 b). Consider first the combination of the utility function (2.14 a) and (2.15 b). By Lemma 2.2, this is the case of $u_x < 0$ and $f_x > 0$. The necessary condition for an optimal sustainable development (2.12) becomes $(\sigma_{xx}^{u} - 1)(\sigma_{cc}^{u} - 1) \leq 0$. Then, $\sigma_{cc}^{u} < 1$ implies $\sigma_{xx}^{u} - 1 \geq 0$, which is not compatible with the concavity of the utility function. Next, consider the combination of (2.14 b) and (2.15 b). If $\sigma_{cc}^{u} < 1$, then $u_x > 0$ by Lemma 2.2 (iii). But, this implies $f_x < 0$, and, by Lemma 2.2 (iii), (2.15 b) is not available. ■

3 Two extensions

Proposition 2.1 shows that, given the model in the previous section, the preference constraint $\sigma_{cc}^{u} \geq 1$ cannot be relaxed with the Cobb–Douglas-type production function that is very often used in the endogenous growth literature. This section extends the previous model, seeking the possibility that the results change. The extension is made in two ways. First, we consider a stock pollution model instead of the flow pollution model. Second, we consider a recursive utility instead of the additively time-separable utility function. In this section, we still keep the assumption of exogenous technological change.

3.1 Stock pollution model

We modify the flow pollution model by incorporating pollution stock P:

$$\max_{c(t),p(t)} \int_0^\infty u\left(c(t), P(t)\right) e^{-\rho t} dt \tag{3.1}$$

$$\text{subject to } \dot{K}(t) = e^{gt} f\left(K(t), x(t)\right) - c(t), \tag{3.2}$$

$$\dot{P}(t) = -\xi P(t) + \zeta x(t), \quad P(t) \geq 0 \tag{3.3}$$

$$K(0) = K > 0,\ P(0) = P > 0 \text{ given.}$$

The pollution stock equation (3.3) is newly introduced, where $\xi > 0$, and $\zeta > 0$ if x is pollution flow, while if x is an environmental service or pollution abatement service, then $\zeta < 0$. The utility and the production functions are assumed to have the same properties as before. But, since P is the pollution stock, $u_P < 0$ holds.[1] The growth rates and the elasticities are denoted as the previous section. The counterpart of Assumption 2 is:

Assumption 2': All the elasticities, $\sigma^u_{cc}, \sigma^u_{PP}, \sigma^u_{cP}, \sigma^u_{Pc}, \sigma^f_{KK}, \sigma^f_{xx}, \sigma^f_{Kx}$, and σ^f_{xK}, are constant.

The associated Hamiltonian is given by:

$$H(c, x, K, P, \lambda, \nu) = u(c, P) + \lambda[e^{gt} f\left(K, x\right) - c] + \nu(-\xi P + \zeta x). \tag{3.4}$$

The first order conditions for interior optimum are:

$$u_c - \lambda = 0; e^{gt}\lambda f_x + \nu\zeta = 0; \dot{\lambda} = \lambda(\rho - e^{gt} f_K); \dot{\nu} = \nu(\rho + \xi) - u_P. \tag{3.5}$$

[1] The model can be modified as an environment stock model if we define the stock E by $E = -P$. Aghion and Howitt (1998, Chapter 5) use this type of model.

From these, in an optimal steady state, it holds that:

$$g_\lambda = -\sigma^u_{cc} g_c + \sigma^u_{cP} g_P; \tag{3.6}$$

$$g_\nu - g_\lambda = g + \sigma^f_{xK} g_K - \sigma^f_{xx} g_x; \tag{3.7}$$

$$g = \sigma^f_{KK} g_K - \sigma^f_{Kx} g_x; \tag{3.8}$$

$$g_\nu = \sigma^u_{Pc} g_c - \sigma^u_{PP} g_P. \tag{3.9}$$

Since $g_K = g_c$ and $g_P = g_x$ in an optimal steady state, these equations imply:

$$(\sigma^u_{PP} + \sigma^u_{cP} - \sigma^f_{xx} - \sigma^f_{Kx}) g_P = (\sigma^u_{cc} + \sigma^u_{Pc} - \sigma^f_{xK} - \sigma^f_{KK}) g_c. \tag{3.10}$$

(3.10) is formally the same as (2.11) and we have the similar conclusion:

Proposition 3.1 *Under Assumptions 1 and 2', if an optimal sustainable development path exists for the stock pollution model (3.1) with $\sigma^u_{cc} < 1$, then the production function is not of Cobb–Douglas type (2.15 b).*

Proof. The proof is essentially the same as that for Proposition 2.1. ■

3.2 Recursive utility model

In this subsection, instead of the additively time-separable utility, we adopt the recursive utility initiated by Koopmans (1960). To do so, we use discrete time $t = 0, 1, 2, ...$ Let $u_t = u(c_t, x_t)$ and $S \subset \mathbb{R}^\infty$ be the space of the streams $(u_t)_{t=1}^\infty$. Let the total utility be given by the function $U : S \to \mathbb{R}$. The total utility is recursive if there exists an aggregator (function) $W : \mathbb{R}^2 \to \mathbb{R}$ such that $U(u_1, u_2, ...) = W(u_1, U(u_2, u_3, ...))$. In order to examine the possibility of relaxing the constraints on the preference with the Cobb–Douglas-type production function, we assume Assumptions 1 and

2, $\sigma^u_{cc} < 1$, and the production function:

$$e^{gt}f(K,x) = \tilde{g}^t K^\alpha x^\beta, \quad \tilde{g} = e^g > 1,\ \alpha,\beta > 0,\ \alpha+\beta \le 1. \tag{3.11}$$

The capital accumulation is given by:

$$K_t = e^{gt}f(K_{t-1}, x_t) - c_t. \tag{3.12}$$

Note that in order for the production function to be concave, x_t should be the pollution flow. Therefore, $u_x < 0$ and in order for the utility function to be concave under the assumption of $\sigma^u_{cc} < 1$, it should take the form of:

$$\left(\frac{c^{1-\sigma^u_{cc}}}{1-\sigma^u_{cc}} - 1\right) - \tilde{\gamma}\frac{x^{1+\omega}}{1+\omega}\ (\tilde{\gamma},\omega > 0). \tag{3.13}$$

(See Lemma 2.2 (iii).)

Denoting by $J(K)$ the maximum total utility when the initial capital stock is K, an optimal capital path $(K^*_t)_{t=0}^\infty$ satisfies the Bellman equation:

$$J(K^*_{t-1}) = W(u(c^*_t, x^*_t), J(K^*_t)) = \max_{c,x,K\ge 0} W(u(c,x), J(K)) \tag{3.14}$$
$$\text{subject to } K = e^{gt}f(K^*_{t-1}, x) - c \ge 0$$

for each $t \ge 1$. Therefore, the associated consumption and pollution flows (c^*_t, x^*_t) satisfy:

$$(c^*_t, x^*_t) = \arg\max_{c,x\ge 0}\{u(c,x) | K^*_t = e^{gt}f(K^*_{t-1}, x) - c \ge 0\}. \tag{3.15}$$

Then, we obtain:

$$0 = u_x(c_t^*, x_t^*) + u_c(c_t^*, x_t^*)e^{gt} f_x(K_{t-1}^*, x_t^*) = -\tilde{\gamma} x_t^{*\omega} + \beta c_t^{*-\sigma_{cc}^u} \tilde{g}^t K_{t-1}^{*\alpha} x_t^{*\beta-1}. \tag{3.16}$$

If the optimal capital path is a balanced growth path, i.e., if there is $\theta > 1$ such that $K_t^* = \theta K_{t-1}^*$ for all $t \geq 1$, then it holds that:

$$\theta = \frac{K_t^*}{K_{t-1}^*} = \frac{e^{gt} f(K_{t-1}^*, x_t^*)}{K_{t-1}^*} - \frac{c_t^*}{K_{t-1}^*} = \frac{\tilde{g}^t K_{t-1}^{*\alpha} x_t^{*\beta}}{K_{t-1}^*} - \frac{c_t^*}{K_{t-1}^*} \tag{3.17}$$

Combine (3.16) and (3.17) to obtain:

$$\theta = \left(\frac{(\tilde{\gamma}/\beta)\, x_t^{*\omega+1}}{c_t^{*1-\sigma_{cc}^u}} - 1 \right) \frac{c_t^*}{K_{t-1}^*}. \tag{3.18}$$

Since c_t^*/K_{t-1}^* is constant on a balanced growth path, (3.18) implies that there is a positive number δ such that:

$$x_t^* = \delta c_t^{*\frac{1-\sigma_{cc}^u}{1+\omega}} = \delta \theta^{\frac{1-\sigma_{cc}^u}{1+\omega}(t-1)} c_1^{*\frac{1-\sigma_{cc}^u}{1+\omega}}. \tag{3.19}$$

That is, the optimal pollution flow x_t^* increases with the growth rate $\theta^{(1-\sigma_{cc}^u)/(1+\omega)}$ and the optimal balanced growth path is not sustainable as far as $\sigma_{cc}^u < 1$. Therefore, we obtain:

Proposition 3.2 *In the case of the recursive utility model, the conclusion in Proposition 2.1 does not change. That is, under Assumptions 1 and 2, if an optimal sustainable development path exists with the utility function satisfying $\sigma_{cc}^u < 1$, then the production function is not of Cobb–Douglas type (2.15 a).*

These two propositions show that it is difficult to relax the preference constraint when the Cobb–Douglas-type production function is employed.

4 An endogenous growth model: Illustration

Proposition 2.1 only shows the possibility of an optimal sustainable development path with $\sigma_{cc}^u < 1$. This section illustrates that it indeed exists. By Proposition 2.1, the production function should be specified as (2.15 a). We consider x to be an environmental service or pollution abatement service (the case of $f_x < 0$) and write the production function as:

$$f(K, x) = AK^\alpha - Bx^\beta, \quad A, B > 0, \alpha \in (0, 1), \beta > 1. \tag{4.1}$$

This choice allows us to use both forms of utility functions (2.14 a) and (2.14 b) without violating their concavity (see Lemma 2.2). We assume that technological progress is made by the accumulation of human capital. We replace the exogenous technological progress e^{gt} in (2.2) with the effective labor input nHL, where H is human capital, L is the total raw labor, and n is the share of the labor input into the final good sector. The accumulation of H enjoys increasing returns to scale. That is, standardizing the amount of the total raw labor as one ($L = 1$), the evolution is given by:

$$\dot{H}(t) = \eta(1 - n(t))H(t), \quad \eta > \rho. \tag{4.2}$$

The production function including technological change is written as:

$$F(K, H, x, n) = (nH)^{1-\alpha} (AK^\alpha - Bx^\beta), \quad A, B > 0, \alpha \in (0, 1), \beta > 1. \tag{4.3}$$

We use the utility functions (2.14 b) with $\sigma_{cc}^u < 1$ and $u_x > 0$:

$$u(c, x) = \frac{\left(cx^\phi\right)^{1-\sigma_{cc}^u}}{1 - \sigma_{cc}^u}, \quad 0 < \phi \le \frac{\sigma_{cc}^u}{1 - \sigma_{cc}^u}, \tag{4.4}$$

where the upper limit of ϕ is imposed to ensure the concavity of the utility function. Later, it becomes clear why we do not adopt another functional form (2.14 a), the additively separable utility function.

Then, our endogenous growth model is given by:

$$\max_{c(t),x(t),n(t)} \int_0^{\infty} u(c(t),x(t))e^{-\rho t}dt \tag{4.5}$$

$$\text{subject to } \dot{K}(t) = F(K(t),H(t),x(t),n(t)) - c(t) \tag{4.6}$$

$$\dot{H}(t) = \eta(1-n(t))H(t), \quad H(t) \geq 0, \ n(t) \in [0,1], \tag{4.7}$$

$$K(0), H(0) > 0 \text{ given,}$$

where u and F are given by (4.4) and (4.3), respectively.

From Lemma 2.1 and (4.3), on a balanced growth path, it follows that:

$$g_K = g_c = g_H = (\beta/\alpha)g_x \text{ and } g_n = 0. \tag{4.8}$$

As seen from (4.8), if there is an optimal balanced growth path with $g_K > 0$, it is an optimal sustainable development path. Since the model (4.5) is a concave problem, if we find a feasible path satisfying a series of the first order conditions and the transversality condition, it is optimal. Letting λ and μ be the costates associated with K and H, respectively, the first order conditions for an interior optimum are given by:

$$u_c(c(t), x(t)) - \lambda(t) = 0; \tag{4.9}$$

$$u_x(c(t), x(t)) - \beta B \lambda(t) x(t)^{\beta-1} (nH(t))^{1-\alpha} = 0; \tag{4.10}$$

$$\lambda(1-\alpha)\,(nH(t))^{-\alpha}\,(AK^{\alpha} - Bx^{\beta}) - \eta\mu(t) = 0; \tag{4.11}$$

$$g_\lambda = \rho - \alpha A\,(nH(t)/K(t))^{1-\alpha}\,; \tag{4.12}$$

$$g_\mu = [\rho - \eta(1-n)] - (n/\mu)\,\lambda(1-\alpha)\,(nH(t))^{-\alpha}\,(AK^{\alpha} - Bx^{\beta}). \tag{4.13}$$

By (4.8) and (4.11), $g_\lambda = g_\mu$. Combine (4.11) and (4.13) to obtain:

$$g_\lambda = g_\mu = [\rho - \eta(1-n)] - n\eta = -(\eta - \rho). \tag{4.14}$$

(4.12) and (4.14) imply:

$$\frac{nH(t)}{K(t)} = \left(\frac{\eta}{\alpha A}\right)^{\frac{1}{1-\alpha}}. \tag{4.15}$$

The time derivatives of (4.9) and (4.10) are written as:

$$-\sigma^u_{cc} g_c + \sigma^u_{cx} g_x = g_\lambda; \tag{4.16}$$

$$\sigma^u_{xc} g_c - \sigma^u_{xx} g_x = g_\lambda + (\beta - 1) g_x + (1-\alpha) g_H, \tag{4.17}$$

respectively. Substitute (4.8) into these equations to obtain:

$$\{[\sigma^u_{xc} - (1-\alpha) - (\alpha/\beta)(\sigma^u_{xx} + (\beta - 1))] - [(\alpha/\beta)\sigma^u_{cx} - \sigma^u_{cc}]\} g_c = 0. \tag{4.18}$$

In order for an optimal sustainable development path to exist, $\{\cdot\}$ on the left hand side of (4.18) must be zero. This condition always holds when the utility function is given by (2.14 b), whereas in the case of the additively separable function (2.14 a), it holds only if σ^u_{xx} satisfies $1-\sigma^u_{xx}=(\beta/\alpha)\,(1-\sigma^u_{cc})$.[2] This is the reason why we have chosen the functional form (2.14 b).

Note that $\sigma^u_{cx}=1-\sigma^u_{xx}=\phi(1-\sigma^u_{cc})$ by Lemma 2.2. Substitute (4.8) and (4.14) into (4.16) to obtain:

$$g_c=\frac{\eta-\rho}{\sigma^u_{cc}-(\alpha/\beta)\phi(1-\sigma^u_{cc})}. \tag{4.19}$$

In order to have a positive growth rate, the denominator in (4.19) must be positive, which imposes a condition on the elasticity:

$$\sigma^u_{cc}>\frac{(\alpha/\beta)\phi}{1+(\alpha/\beta)\phi}=1-\frac{1}{1+(\alpha/\beta)\phi}. \tag{4.20}$$

Note that this condition can be compatible with $\sigma^u_{cc}<1$.

Since we have derived all growth rates that are given by (4.8), (4.14) and (4.19), we turn to the levels of the variables on an optimal sustainable development path. From (4.7), (4.8) and (4.19), the labor share n is given by:

$$n=1-\frac{1-\rho/\eta}{\sigma^u_{cc}-(\alpha/\beta)\phi(1-\sigma^u_{cc})}. \tag{4.21}$$

The share n should be positive, which imposes another condition on the elasticity σ^u_{cc}:

$$\sigma^u_{cc}>\frac{1+(\alpha/\beta)\phi-\rho/\eta}{1+(\alpha/\beta)\phi}=1-\frac{\rho/\eta}{1+(\alpha/\beta)\phi}. \tag{4.22}$$

[2] Usually, an optimal balanced growth path appears in the circumstances with the combination of homogeneous utility and production functions. In order to obtain such functions, appropriate monotone transformations of the variables are required sometimes. In our case, x needs to be transformed to $\tilde{x}=(x)^{\beta/\alpha}$ following a request from the production function side. In the case of the additively separable utility function, its homogeneity is satisfied only if the functional form is given by:

$$u(c,x)=c^{1-\sigma^u_{cc}}+\gamma x^{1-\sigma^u_{xx}}=c^{1-\sigma^u_{cc}}+\gamma\left[x^{(\beta/\alpha)}\right]^{1-\sigma^u_{cc}}=c^{1-\sigma^u_{cc}}+\gamma\tilde{x}^{1-\sigma^u_{cc}}.$$

:

Note that the condition (4.22) is still compatible with $\sigma^u_{cc} < 1$, although (4.22) is more stringent than (4.20). From (4.15) and (4.21), $H(t)/K(t)$ is given by:

$$\frac{H(t)}{K(t)} = n\left(\frac{\eta}{\alpha A}\right)^{\frac{1}{1-\alpha}} = \left(1 - \frac{1-\rho/\eta}{\sigma^u_{cc} - (\alpha/\beta)\phi(1-\sigma^u_{cc})}\right)^{-1}\left(\frac{\eta}{\alpha A}\right)^{\frac{1}{1-\alpha}} > 0. \tag{4.23}$$

From (4.9), (4.10) and (4.15), we obtain:

$$\frac{x(t)^\beta}{K(t)^\alpha}\frac{K(t)}{c(t)} = \frac{\alpha\phi A}{\beta\eta B}. \tag{4.24}$$

Using (4.15) and (4.24), the capital accumulation equation (4.6) is rewritten as:

$$g_K = \left(\frac{nH(t)}{K(t)}\right)^{1-\alpha}\left(A - B\frac{x(t)^\beta}{K(t)^\alpha}\right) - \frac{c(t)}{K(t)} = \left(\frac{\eta}{\alpha}\right)\left(1 - \frac{\alpha\phi}{\beta\eta}\frac{c(t)}{K(t)}\right) - \frac{c(t)}{K(t)} \tag{4.25}$$

From (4.19) and (4.25), we obtain:

$$\frac{c(t)}{K(t)} = \left(1 + \frac{\phi}{\beta}\right)^{-1}\left(\frac{\eta}{\alpha} - \frac{\eta-\rho}{\sigma^u_{cc} - (\alpha/\beta)\phi(1-\sigma^u_{cc})}\right). \tag{4.26}$$

In order for the consumption–capital ratio to be positive, it must hold that:

$$\frac{\eta}{\alpha} > \frac{\eta-\rho}{\sigma^u_{cc} - (\alpha/\beta)\phi(1-\sigma^u_{cc})}. \tag{4.27}$$

This inequality restricts the values of the elasticity σ^u_{cc} to:

$$\sigma^u_{cc} > 1 - \frac{\alpha\rho + (1-\alpha)\eta}{\eta(1+(\alpha/\beta)\phi)}. \tag{4.28}$$

Note that this condition is compatible with $\sigma^u_{cc} < 1$, too. The (modified) environmental service-capital ratio is given by (4.24) and (4.26):

$$\frac{x(t)^{\beta/\alpha}}{K(t)} = \left(\frac{\alpha\phi A}{\beta\eta B}\cdot\frac{c(t)}{K(t)}\right)^{1/\alpha} = \left[\frac{\phi A}{(1+\phi)B}\left(1 - \frac{\alpha(1-\rho/\eta)}{\sigma_{cc}^{u} - (\alpha/\beta)\phi(1-\sigma_{cc}^{u})}\right)\right]^{1/\alpha}. \tag{4.29}$$

Finally, we turn to the transversality condition:[3]

$$\lim_{t\to\infty} e^{-\rho t}\lambda(t)K(t) = \lim_{t\to\infty}\lambda(0)K(0)\exp\left[-\left(\eta - \frac{\eta-\rho}{\sigma_{cc}^{u} - (\alpha/\beta)\phi(1-\sigma_{cc}^{u})}\right)t\right] \tag{4.30}$$

which follows from (4.14) and (4.19). By (4.22), at the limit (4.30) converges to zero. From (4.8) and (4.14), another transversality condition also holds: $\lim_{t\to\infty} e^{-\rho t}\mu(t)H(t) = 0$.

Gathering all the above results, we obtain:

Proposition 4.1 *For the endogenous growth model (4.5), there exists an optimal sustainable development path if the elasticity of the marginal utility of consumption satisfies:*

$$\sigma_{cc}^{u} > 1 - \frac{\rho/\eta}{1+(\alpha/\beta)\phi}. \tag{4.31}$$

Proof. From (4.22) and (4.28), σ_{cc}^{u} must satisfy:

$$\sigma_{cc}^{u} > \max\left\{1 - \frac{\rho}{\eta\,(1+(\alpha/\beta)\phi)}, 1 - \frac{\alpha\rho + (1-\alpha)\eta}{\eta(1+(\alpha/\beta)\phi)}\right\}.$$

Then the result follows from $\eta > \rho$. ■

As Proposition 4.1 shows, the preference constraint for sustainable development to be optimal can be relaxed from $\sigma_{cc}^{u} \geq 1$ to (4.31). In order to investigate the implication of (4.31), substitute

[3] For an interior steady state path, the transversality condition is not only sufficient but also necessary for the optimum. See Kamihigashi (2001).

$\phi = (1 - \sigma^u_{xx})/(1 - \sigma^u_{cc})$ into it and we obtain:

$$\sigma^u_{cc} > (1 - \rho/\eta) + (\alpha/\beta)(1 - \sigma^u_{xx}). \tag{4.32}$$

The lower limit (the right-hand side of (4.32)) increases with the productivity parameter of human capital η and the ratio of the production elasticities α/β. These parameters also increase the economic growth rate (see (4.19)). This indicates that the higher the growth potential in the production technology, the harder it is for the preference to satisfy the elasticity condition (4.31).

In the rest of this section, we consider the production function (4.3), because it is not usual and needs some interpretation. First, we transform the environmental service or the pollution abatement service x to $\tilde{x} = x^{\beta/\alpha}$. Define the capital *as a production factor* $\tilde{K}$ by:

$$\tilde{K} = \left(AK^\alpha - Bx^\beta\right)^{1/\alpha} = \left(AK^\alpha - B\tilde{x}^\alpha\right)^{1/\alpha}. \tag{4.33}$$

Then, we can rewrite (4.3) as a standard production function: $(nH)^{1-\alpha}\tilde{K}^\alpha$. On the other hand, the definitional identity of $\tilde{K}$ (4.33) gives the relationship between the production factor $\tilde{K}$ and the environmental service after the transformation $\tilde{x}$:

$$K = \left[A^{-1}\tilde{K}^\alpha + (B/A)\tilde{x}^\alpha\right]^{1/\alpha}. \tag{4.34}$$

This is the very familiar CES function, but it should be named the constant elasticity of *transformation* (CET) function, since the arguments of the right-hand side are not inputs, but rather outputs produced from the capital stock K. As an unusual point, since we assume $\alpha \in (0, 1)$, the production frontier is convex to the origin on the $\tilde{x} - \tilde{K}$ coordinate. On the original $x - \tilde{K}$ coordinate, however, they are concave as far as x is not so large relative to K, satisfying $x^\beta <$

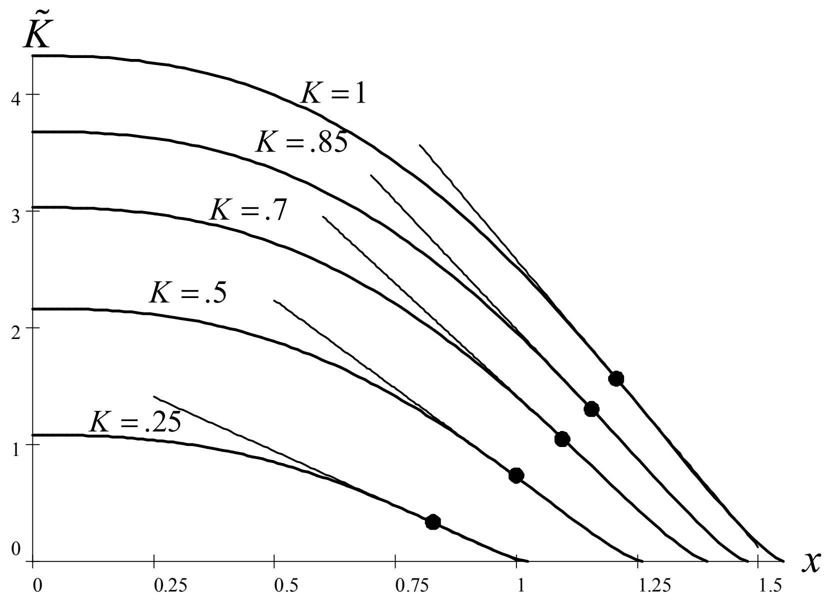


Figure 1: Production frontiers and optimal sustainable development.

$(A/B)\left((\beta-\alpha)/(\alpha\beta-\alpha)\right)K^{\alpha}$.[4] Figure 1 depicts some production frontiers and the associated output levels on the optimal sustainable development path.[5]

Note that the elasticity of transformation in (4.34) is $1/(1-\alpha)$. Then, Proposition 4.1 is interpreted as follows. The preference constraint $\sigma_{cc}^{u} \geq 1$ is relaxed if the production technology satisfies the condition that the elasticity of transformation to capital as the production factor and the environmental service (or pollution abatement service), after an appropriate monotone transformation, is greater than one. The ineqality (4.31) in Proposition 4.1 indicates that the easier the technological transformation, the less severe is the preference constraint. Note that at the limit $\alpha \to 1$, the endogenous growth model (4.5) coincides with the trivial model (1.1) mentioned in the Introduction.

[4] Also note that at the limit $\alpha \to 0$, different from the usual case, the function (4.34) is not well defined. To see this, express the equation (4.34) using x instead of $\tilde{x}$: $K = \left[A^{-1}\tilde{K}^{\alpha} + (B/A)x^{\beta}\right]^{1/\alpha}$.

[5] The parameter values are $\rho = 0.03, \sigma_{cc}^{u} = 0.8, \phi = 2, \eta = 0.0725, \alpha = 0.75, \beta = 2.5, A = 3$, and $B = 1$.

5 Conclusion

In this paper, we have considered the necessary condition imposed on the preference for sustainable development to be optimal. The necessity of the preference constraint $\sigma^u_{cc} \geq 1$ depends on the production technology. If the production function is of Cobb–Douglas type, it is necessary. On the other hand, if the production function takes the form of (4.3), then the constraint is relaxed. This production function has the property that the elasticity of transformation to the production factor and the environmental service (or the pollution abatement service), after an appropriate monotone transformation, is greater than one. There is a substitution relationship between the preference constraint and the elasticity of transformation in the production technology.

References

[1] Akao, K., Managi, S., 2007 Feasibility and optimality of sustainable growth under materials balance, Journal of Economic Dynamics & Control 31, 3778–3790.

[2] Aghion, P., Howitt, P., 1998. Endogenous Growth Theory. MIT Press, Cambridge, MA.

[3] Kamihigashi, T., 2001, Necessity of transversality conditions for infinite horizon problems, Econometrica 69, 995–1012.

[4] Koopmans, T.C., 1960. Stationary ordinal utility and impatience, Econometrica 28, 387–309.

[5] Pearce, D., Markandya, A., Barbier, E.B., 1989. Blueprint for a Green Economy, Earthscan, London.

[6] Smulders, S., 1999. Endogenous growth theory and the environment, in: van den Berg, J.C.J.M. (Eds.), Handbook of Environmental and Resource Economics, Edward Elgar, Cheltenham, pp. 610–621.

Critical Natural Capital and Sustainable Development: The Theoretical Basis and Challenges

Kazuki Kagohashi and Kazuhiro Ueta

Abstract

This paper aims to clarify the theoretical basis of "critical natural capital" (CNC) in relation to the economic theory of sustainable development (SD). Regarding CNC as a key concept to achieve SD, we examine some of the challenges posed to operationalization of the concept of CNC.

We classify the economic theory of SD into four approaches to sustainability, namely, (1) Solow–Hartwick's sustainability, (2) Daly's sustainability, (3) Ekins' sustainability, and (4) Pearce–Turner's sustainability, and analyze how each approach interprets natural capital and how such interpretation is derived from a theoretical framework.

According to the analysis, in Solow–Hartwick's sustainability, natural capital is captured as a stock which constitutes a part of input to production. CNC is limited to an input without which production of consumer goods becomes impossible. In Daly's sustainability, natural capital is seen as a stock of low entropy resources. As the assimilative capacity of the environment is not included in natural capital, CNC is limited exclusively to the low entropy resources put into the economic process. Such a stock of low entropy resources has a property that its loss decreases the utility of people infinitely when the critical level (threshold) of the stock is unmet. In Ekins' sustainability, CNC is regarded as a stock that performs critical environmental functions and has properties such as non-substitutability and irreversible and immoderate losses. In Pearce–Turner's sustainability, CNC is considered as a stock that provides a life-support function. While Solow–Hartwick's sustainability and Daly's sustainability differ in the way of capturing natural capital, they both limit the concept of CNC to input to production. Both Ekins' sustainability and Pearce–Turner's sustainability involve the problem of determining the critical level (threshold) of natural capital.

The results of this research implies, first, the theoretical differences among the four approaches to sustainability come from differences in not only the concepts and interpretations of both natural capital and CNC, but also the answer to the fundamental question of what is to be sustained in SD. Second, every approach has the common feature of *not denying* the "constant capital rule" as long as it is regarded as a minimum necessary condition for the achievement of SD. Third, what is important is the determination of the critical level (threshold) of natural capital under uncertainty such that CNC contributes to policy making towards SD, and in particular we ought to examine how to take into account the social aspects of CNC.

1. Introduction

Sustainable Development (SD) is classified into two paradigms labeled as "weak sustainability" and "strong sustainability". While weak sustainability regards natural capital as a substitutable asset for manufactured capital, strong sustainability emphasizes the non-substitutability of natural capital (Pearce and Turner 1990; Neumayer 2003). The concept of "critical natural capital" (CNC) was introduced to represent not only the non-substitutability of natural capital, but also the state of natural resources and the environment that the current generation ought to maintain for the sake of future generations. The economic theory of SD has developed for decades through discussions of these issues.[1]

Pearce et al. (1993) proposed the concept of CNC as ecological assets which are either essential for human well-being or survival. Subsequently, CNC was perceived as a concept for operationalizing the paradigm of strong sustainability and was developed conceptually in a set of study projects (the CRITINC Project) which led to the publication of a special issue of *Ecological Economics* in 2003 (e.g. Ekins et al. 2003; De Groot et al. 2003). Recently, De Groot et al. (2006) discussed the indicators of CNC and Brand (2009) proposed that the information on ecological resilience should be incorporated into the evaluation of CNC.[2]

However, the concept of CNC is utilized by the advocates of strong sustainability without any firm theoretical basis and is defined or interpreted in a variety of ways. In addition, the circumstance of the introduction of the concept is neglected, and CNC tends to become a jargon representing the non-substitutability of natural capital in the paradigm of strong sustainability. CNC should be interpreted not as a source of conflict, but as a basic concept that encourages dialogue between advocates of weak sustainability and strong sustainability because CNC intrinsically poses an important question for both paradigms of sustainability.

The problem is that the theoretical basis of CNC has not been examined at all. It is necessary to examine the conceptual possibility and theoretical basis of CNC by reviewing how CNC was introduced, how it has been developed conceptually, and how it

[1] Regarding the development of the concept of CNC, see Pearce et al. (1993); Noel and O'Connor (1998); MacDonald et al.(1999); Chiesura and De Groot (2003); De Groot et al. (2003); Douguet and O'Connor (2003); Deustch et al. (2003); Ekins (2003a,b); Ekins et al. (2003); Ekins and Simon (2003); Ozkaynak et al. (2004); Farley (2008); and Brand (2009).

[2] It is generally considered that CNC should be evaluated in physical terms, not in monetary terms. The reasons for this are that the effect of the loss of CNC is quite uncertain because the ecosystem has aspects of interdependency and complexity (e.g. Ekins 2003a,b; Ozkaynak et al. 2004), and that it is useless to treat CNC as some object in trade-offs because CNC exhibits an absolute constraint (e.g. MacDonald et al. 1999).

can be captured in the economic theory of SD.

The aims of this paper are threefold: (1) to identify the theoretical background of the introduction of CNC, 2) to examine the relationship between each existing economic theory of SD and natural capital by surveying the purposes and approaches of each theory and (3) to clarify the theoretical basis of and challenges posed to CNC.

This paper takes three steps in analyzing the above research issues. First, we classify the economic theories of SD into four approaches to sustainability by their purpose and method, that is, (1) Solow/Hartwick's sustainability, (2) Daly's sustainability, (3) Ekins' sustainability and (4) Pearce/Turner's sustainability. Second, we verify the theoretical framework behind each approach and analyze how natural capital is captured in each theoretical framework. Third, based on the result from the second step, we examine how CNC can be derived from the theoretical basis of each approach to sustainability.

2. Theoretical debate on substitutability of natural capital

The economic theory of SD developed primarily through the debate on the substitutability of natural and man-made capital. The concept of CNC was born from the question that arises in the debate: What, in terms of economic theory, are the natural resources or environment required for achieving sustainable economic development?

The debate surrounding the substitutability of natural resources finds its source in the study by Meadows (1972), who argued that the world economy would reach limits set by the depletion of non-renewable resources (Turner 1997, p.300). In contrast to the negative stance of Meadows (1972) on the possibility of sustainable production of consumer goods, Solow (1974), Hartwick (1977, 1978a), and Stiglitz (1979) argued from the neoclassical economics standpoint that sustainable economic growth could be made possible by reinvesting non-renewable resource rents into man-made capital. The debate here was regarding the elasticity of substitution between man-made and non-renewable resources in the production function, through appropriate specification of the production function (Pearce et al. 1994, p.469), and was an exploration of the conditions under which non-renewable resources would not become a check on the economic growth, i.e. a discussion of the conditions under which non-renewable resources become non-essential.

2.1. Elasticity of substitution of non-renewable resources

Solow (1974) offered the following three conditions by which an economy possessing manufactured capital and non-renewable resources as production inputs can indefinitely sustain consumption: (1) elasticity of substitution is greater than 1; (2) when elasticity of substitution is 1, the contribution of manufactured capital in producing output is greater than that of non-renewable resources; and (3) the productivity of stocks of natural capital rises through technological progress. Furthermore, in the case of (2), Hartwick (1977, 1978a) showed that the reinvestment of rents gained from non-renewable resources into manufactured capital allows the enjoyment of a constant level of consumption over time (i.e. the Hartwick rule). Upon the expansion (Hartwick 1978b) of the Hartwick rule to renewable resources, Solow (1986) showed that the Hartwick rule is to be interpreted as holding the total stock of capital intact and treating consumption as the interest rate (i.e. discount rate) on that stock (Pearce et al. 1994; Hartwick 1994). While this is termed as weak sustainability[3], in general, SD is recognized as the development path by which the total stock of capital is maintained by the reinvestment of rents from natural capital into the accumulation of man-made capital under the Hartwick rule.

However, it has been noted that as a condition for achieving the constant flow of consumption, Hartwick's rule is not valid when the elasticity of substitution between man-made capital and non-renewable resources is less than 1 (Maler 1986; Gutes 1996). It has been reported (Turner 1997) that according to previous empirical studies, while the elasticity of substitution for mineral resources including iron, copper and aluminium was more than 1 (Brown and Field 1979), it was less than 1 for 'critical' and strategic materials such as titanium, beryllium, and germanium (Deadman and Turner 1988).

2.2. Physical substitutability of non-renewable resources

In contrast to Solow–Hartwick's optimistic outlook for economic growth with respect to sustainability, Georgescu-Roegen (1971, 1979) and Daly (1974) agree with the opinion of Meadows (1972) and assert that resource constraints are an absolute and that perpetual economic growth is totally impossible. The question here is the physical substitutability between non-renewable resources and man-made capital.

Georgescu-Roegen (1979) critiqued the Solow–Hartwick–Stiglitz model as follows.

[3] Solow's sustainability is sometimes called 'very weak sustainability' (see Pearce et al. 1993).

Letting Y denote product output, and with $F(K, R)$ as a Cobb–Douglas production function[4],

$$Y = F(K, R) = K(t)^{\alpha}R(t)^{\beta}$$

,

where $\alpha > 0$, $\beta > 0$, $\alpha + \beta = 1$ and K and R denote man-made capital and natural resource inputs, respectively. This Cobb–Douglas production function can be rewritten as:

$$R(t)^{\beta} = \frac{Y}{K(t)^{\alpha}}$$

.

This means that if $K(t)$ is sufficiently large, 'we can obtain a constant annual product indefinitely even from a very small stock of resources $R > 0$ and R may be as small as we wish' (Georgescu-Roegen 1979, p.98). However, in reality, we need greater R when we accumulate man-made capital, and if $K(t) \to \infty$, $R(t)$ will be depleted rapidly.

Georgescu-Roegen realized that the economic process is a process of increasing entropy (Georgescu-Roegen 1971). Low entropy in an isolated system flows one-way into high entropy, and the energy dissipated cannot be restored. Under the second law of thermodynamics (the entropy principle), the process of production in an economy should be viewed as an irreversible conversion process of low entropy into high entropy; thus, criticism focused on how this physical aspect gets abstracted away in the production function of neoclassical economics (Georgescu-Roegen 1971, pp.358–408). Based on this perspective, Georgescu-Roegen strongly criticized Solow (1974) and Stiglitz (1979) as follows:

> 'Solow and Stiglitz could not have come out with their conjuring trick had they borne in mind, first, that any material process consists in the transformation of some materials into others (the flow elements) by some agents (the fund elements), and second, that natural resources are the very sap of the economic process.' (Georgescu-Roegen 1979, p.98)

He charges that the Solow–Stiglitz model is 'an earthly Garden of Eden' (Georgescu-Roegen 1979, p.98) as it disregards physical reality, i.e. based on the second law of thermodynamics, accumulation of man-made capital cannot create the material

[4] Labour is abbreviated from production function here for simplicity.

on which it works and can only diminish the amount of waste in production.

While Georgescu-Roegen did not explicitly touch upon SD, his awareness of the impossibility of production without the input of natural resources from the perspective of physical laws was picked up by the pioneers of ecological economics such as Herman Daly and Robert Costanza, and became the theoretical basis for strong sustainability[5].

2.3. Introducing the concept of Critical Natural Capital

The debate over the substitutability of non-renewable resources occurs mainly between neoclassical economics, which argues for the elasticity of substitution in the production function, and thermodynamic economics, which asserts the limits of physical substitutability from the perspective of the laws of thermodynamics. Amidst this, the debate over substitutability has extended to encompass renewable resources as a target (see for example, Hartwick 1978b, Solow 1986, Maler 1986, Daly 1979, and Daly 1990).

What should be noted here is that in the debate over the possibility of sustainable production of consumer goods taking natural resources as production inputs, the question 'What is to be sustained?' has materialized as the SD argument's ultimate point of discussion. The concept of SD was already under development in the 1970s (although not called as such, as it was officially presented in the Brundtland Commission report of 1987). In contrast to Solow and Hartwick claimed that production of consumer goods can be maintained even without natural resources, Georgescu-Roegen and Daly put forth the assertion that economic processes cannot hold without natural resources. To the question 'What is to be sustained?', Solow and Hartwick did not give a special position to natural resources, whereas Daly and Georgescu-Roegen took the stance that maintaining natural resources is an absolute necessity. As the debate between the two sides was fixed on the substitutability between natural resources and man-made capital in the production function, the substitutability of natural resources became the focus of debate; however, as natural resources are counted as one type of capital in the production function, the key issue in the SD theory today, the substitutability of natural capital, was actually born in the 1970s.

D. Pearce and R. Turner took the discussion of the substitutability of natural resources, and with recognition of the importance of the physical substitutability issue

[5] For example, regarding the entropy principle, Costanza and Daly (1992) state: 'Manufactured capital (MC), human capital (HC), and renewable natural capital (RNC) decay at significant rates by the second law of thermodynamics and must constantly be maintained. Nonrenewable natural capital (NNC) also decays, but the rate is so slow relative to MC and RNC that this can be ignored'. (Costanza and Daly 1992, p.38)

as raised by thermodynamic economics, addressed SD from the direction of a modified framework of Solow and Hartwick's capital theory (Turner 1993, p.11). With the studies by Solow (1974, 1986) and Hartwick (1977, 1978a) as a theoretical foundation, they posed the constant capital rule that states that the non-declining total capital stock is necessary condition to achieve SD (Pearce et al. 1994, p.463; Pearce and Atkinson 1993). Using the Hartwick rule for theoretical support, the constant capital rule joined SD with economic theory and conferred a solid theoretical foundation upon which to evaluate SD. Concurrently, however, Pearce et al. (1994) recognized problems with the constant capital rule as follows:

> 'This criterion corresponds to the 'Hartwick-Solow' requirement that the total capital stock be non-declining, so that consumption may also be non-declining. Moreover, as the criterion involves only aggregate measures of manufactured and natural capital, it assumes not only substitutability between these two categories, but also substitutability within the categories. In line with the weak sustainability framework, no requirement for the minimal retention of any particular type of natural capital is made.' (Pearce et al. 1994, p.467)

Therefore, when the constant capital rule, which is the postulate for weak sustainability, has no practical relevance, then the rule that should be applied becomes the constant natural capital rule, which is the postulate for strong sustainability, with the target of application conceptualized as CNC.

Pearce et al. (1993) state, 'We may therefore designate those ecological assets which are essential in either sense as being critical natural capital. They are critical either to well-being or to survival' (Pearce et al. 1993, p.16), for the first time defining CNC in clear form as the ecological assets essential for human survival and well-being[6]. In addition, Turner et al. (1994b, p.56) cite biogeochemical cycling as an example more concretely connecting the human survival aspect of CNC to life support services, and as examples of CNC connected to human well-being, landscape, space, relative peace, and quiet (environment)[7]. As seen later, after CNC was defined by Pearce and Turner, CNC was further given definition by various commentators (also Appendix).

---

[6] In Pearce et al. (1993) and Pearce and Warford (1993) the term 'critical capital' appears. In connection with Maler (1986), this requires that stocks be preserved not at the aggregate level but at the sectoral level (Pearce et al. 1993, p.64). Dubourg (1992, 1993) also stated that fresh water is an example of critical capital. In this way, critical capital can be positioned as a forerunner of CNC or as a concept with equivalent meaning.

[7] The view of life-support functions as 'critical' can also be seen in Turner (1997, p.301).

3. Four Approaches to Sustainability and Natural Capital

While the question of what needs to be sustained to achieve SD is deeply connected to individual commentators' SD theories, we will address four approaches to sustainability: (1) Solow–Hartwick's sustainability; (2) Daly's sustainability; (3) Ekins' sustainability; and (4) Pearce–Turner's sustainability. As already mentioned, (1) Solow–Hartwick's sustainability and (2) Daly's sustainability are rooted in Meadows (1972) and added to the debate over the possibility of sustained production of consumer goods; as these predated the Brundtland Commission report in 1987 that officially presented the concept of SD, they can be labelled as pioneering approaches to sustainability in SD theory. (3) Ekins' sustainability and (4) Pearce–Turner's sustainability are the approaches to sustainability that deepened the theory of SD after 1987; the latter was the first to suggest the concept of CNC, while the former is characterized by having sought to deepen the CNC concept.

3.1. Solow–Hartwick's Sustainability

3.1.1. Recognition of SD

The optimal depletion of exhaustible resource model by Solow (1974; 1986), Hartwick (1977; 1978a,b) and Dasgupta and Heal (1979) is expressed by the following maximization problem (Perman et al 1999, p.160):

Select values for the choice variables $\mathrm{C_t}$ and $\mathrm{R_t}$ for $\mathrm{t} = 0, \cdots, \infty$ to maximize

$$\max W = \int_{t=0}^{t=\infty} U(C_t) e^{-\rho t} dt \tag{1}$$

$$\text{s.t.} \quad \dot{S}_t = -R_t \ , \tag{2}$$

$$\dot{K}_t = Q(K_t, R_t) - C_t \tag{3}$$

where choice variables C_t and R_t are consumption and depletion of non-renewable resources, respectively, W is social welfare function, $U(C_t)$ is aggregate utility in period t, ρ is discount rate, $Q(K_t, R_t)$ is production function and K_t is manufactured capital.

Solow–Hartwick interpret SD as maintaining constant or non-declining consumption over an infinite time horizon, and analyse the conditions under which non-renewable resources are non-essential as inputs in the production process. Regarding the meaning of 'essential' here, R is essential if $\mathrm{Q(K, R = 0) = 0}$ for any value of K (Perman et al. 1999, p.151). In Solow–Hartwick's sustainability, the only utility function variable in the objective function is consumer goods; thus, in the production function that expresses the consumer goods production process, if $R_t = 0$ and if $Q(K_t, R_t) = 0$ is true (and therefore non-renewable resources are essential), then maintaining constant or non-declining consumption over an infinite time horizon is not possible[8]. Therefore, analysis was focused on the conditions under which non-renewable resources do not become essential in the production function.

3.1.2. Conditions for SD

Next, we turn to the question of how we can determine whether non-renewable resources are essential or not.

Let ρ denote the discount rate and $Q(K_t, R_t)$ in equation (3) is the CES production function as:

$$Q(K_t, R_t) = A(\alpha K^{-\rho} + \beta R^{-\rho})^{-1/\rho} \tag{4}$$

where $\mathrm{A},\ \alpha,\ \beta > 0,\ \alpha + \beta = 1,\ -1 < \rho \neq 0$.

From equation (4), we see that non-renewable resources are essential if $\rho > 0$ and non-essential if $\rho < 0$. The elasticity of substitution in the CES production functions is expressed as follows (Chiang and Wainwright 2004, p.399; Perman et al. 1999, p.152):

$$\sigma = \frac{\dfrac{d(K/R)}{K/R}}{\dfrac{d(Q_R/Q_K)}{Q_R/Q_K}} = \frac{1}{1+\rho} \tag{5}$$

where $\mathrm{Q_R}$ is the marginal product of non-renewable resources and $\mathrm{Q_K}$ is the marginal product of manufactured capital, i.e. $\mathrm{Q_R} = \partial \mathrm{Q}/\partial \mathrm{R}$ and $\mathrm{Q_K} = \partial \mathrm{Q}/\partial \mathrm{K}$, respectively.

Thus, conditions for the essentiality of non-renewable resources are expressed as follows:

$$R_t \text{ is essential if } 0 < \sigma < 1 \leftrightarrow 0 < \rho < \infty \tag{6}$$

$$R_t \text{ is non-essential if } \sigma > 1 \leftrightarrow -1 < \rho < 0 \tag{7}$$

$\sigma = 1$ means unitary elasticity of substitution and corresponds to the Cobb–Douglas production function form[9] (Chiang and Wainwright 2004, p.399; Dasgupta and Heal

---

[8] With regard to the definition of essentiality of non-renewable resources, Dasgupta and Heal (1979) state unequivocally, 'We shall therefore regard an exhaustible resource as being inessential if there is a feasible programme along which consumption is bounded away from zero; or in other words, if a positive sustainable level of consumption is feasible. Similarly, we shall regard a resource as essential if feasible consumption must necessarily decline to zero in the long run. In short, doom cannot be avoided in the long run if there are exhaustible resources that are essential' (Dasgupta and Heal 1979, pp.198–199).

[9] Dividing both sides of $\mathrm{Q} = \mathrm{A}(\alpha \mathrm{K}^{-\rho} + \beta \mathrm{R}^{-\rho})^{-1/\rho}$ by A and taking the logarithm yields $\ln\frac{\mathrm{Q}}{\mathrm{A}} =$

1979, pp.199-201) such as:

$$Q(K_t, R_t) = AK^{\alpha}R^{\beta} \tag{8}$$

As $Q(K_t, 0) = 0$ in equation (8), non-renewable resources are always essential in the Cobb–Douglass production function. However, Dasgupta and Heal (1979) showed that if the condition $\alpha > \beta$ is satisfied, i.e. elasticity of output with respect to man-made capital is higher than that with respect to the resource inputs, then non-renewable resources become non-essential, and conversely, if $\alpha \leq \beta$ then non-renewable resources become essential and constant consumption cannot be achieved (Dasgupta and Heal 1979, pp.201–204).

$$R_t \text{ is essential if } \sigma = 1 \text{ and } \alpha \leq \beta \tag{9}$$

$$R_t \text{ is non-essential if } \sigma = 1 \text{ and } \alpha > \beta \tag{10}$$

As clarified by the above statements, whether or not non-renewable resources are essential in the production function is determined by the elasticity of substitution with man-made capital[10]. Production inputs are essential when elasticity of substitution is less than 1, and non-essential when it is greater than 1. When elasticity of substitution is 1, essentiality is not determined *a priori* by elasticity of substitution alone, but rather by the relative ratio of elasticity of output with respect to man-made capital (share of man-made capital) and elasticity of output with respect to resource input (share of resource input).

In the graph below, essentiality of a natural resource input can be confirmed easily by whether isoquants between natural resource and man-made capital hit the resource axis (Stiglitz 1979, p.41).

$-\frac{\ln[\alpha K^{-\rho}+\beta R^{-\rho}]}{\rho}$.

Setting the numerator as $m(\rho)$ and the denominator as $n(\rho)$,

$n'(\rho) = 1$, $m'(\rho) = \frac{-1}{[\alpha K^{-\rho}+\beta R^{-\rho}]}\frac{d}{d\rho}[\alpha K^{-\rho} + \beta R^{-\rho}] = \frac{\alpha K^{-\rho}\ln K+\beta R^{-\rho}\ln R}{[\alpha K^{-\rho}+\beta R^{-\rho}]}$ $(\because \frac{d}{dt}x^{f(t)} = f'(t)x^{f(t)}\ln x)$

Using L'Hospital's formula, $\lim_{\rho\to 0}\ln\frac{Q}{A} = \frac{m'(\rho)}{n'(\rho)} = \frac{\alpha\ln K+\beta\ln R}{\alpha+\beta} = \alpha\ln K + \beta\ln R = \ln(K^{\alpha}R^{\beta})$

As $\lim_{\rho\to 0} Q = \lim_{\rho\to 0} Ae^{\ln(Q/A)} = Ae^{\lim_{\rho\to 0}\ln(Q/A)}$ here, and from the above result $\lim_{\rho\to 0}\ln\frac{Q}{A} = \ln(K^{\alpha}R^{\beta})$, we get $\lim_{\rho\to 0} Q = AK^{\alpha}R^{\beta}$.

[10] While the above discussion does not consider the depreciation of man-made capital, what would be the effect on the essentiality discussion of doing so? Dasgupta and Heal (1979) have analysed this point. The case in which depreciation will increase at the same rate over time (decays linearly in time) and the case in which depreciation is proportional to output (proportional to gross output) do not have an impact on the essentiality discussion, but if depreciation advances by a fixed fraction in each time period (radioactive decay; a fixed fraction of existing stock of fixed capital is depleted at each instant), then in a Cobb–Douglass function ($\alpha > \beta$) per formula (8), non-renewable resources become essential and consumption level will also eventually fall to zero (Dasgupta and Heal 1979, p.226). However, as such radioactive decay is 'highly unrealistic' (Dasgupta and Heal 1979, p.226), the depreciation of man-made capital is not a major issue in the discussion of essentiality.

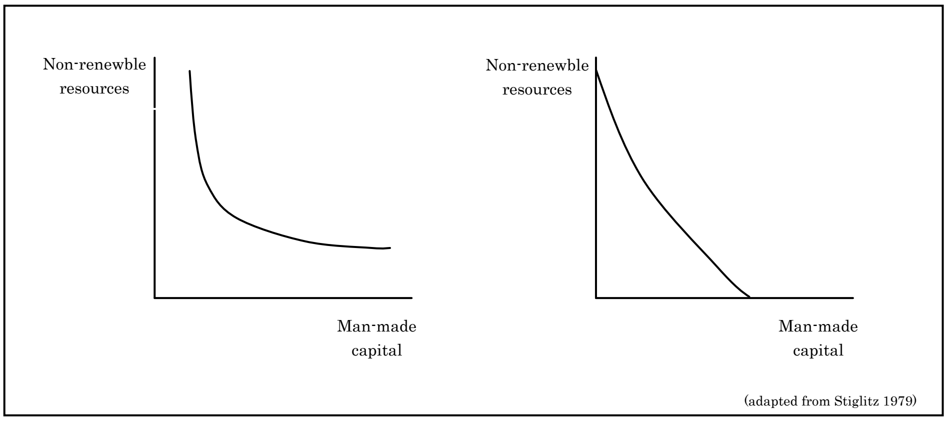


Fig. 1 Essentiality of non-renewable resources

The two figures above exhibit two simple cases in which a natural resource is either essential (left-hand side) or non-essential (right-hand side).

3.1.3. The positioning of natural capital

In the Solow–Hartwick framework, non-renewable resources are positioned as production inputs. As we saw in the previous section, in the Solow–Hartwick framework, production inputs are positioned as natural capital and have assumed perfect substitutability with man-made capital; this gave rise to sharp criticism from Geourgescu-Roegen. When equation (7) is valid, $K(t)$ and $R(t)$, capital and non-renewable resources, are perfectly substitutable; however, the idea ($F(K,0) > 0$) of production without non-renewable resources is criticized as inconsistent with the first law of thermodynamics (law of conservation of energy). Other criticisms (such as Victor 1991, p.210; Pearce and Atkinson 1993, p.103) claim that when the scope of application of the Solow–Hartwick concept of natural capital is expanded from natural resources to the natural environment, the unrealistic conclusion arises that even the environment is substitutable with man-made capital. Doubt is also raised over the validity of the concept of 'capital' that takes natural resources or the environment as reproducible.

3.2. Daly's sustainability

H. Daly directs severe criticism at Solow–Hartwick's sustainability. Based on the theoretical framework of thermodynamic economics built by N. Georgescu-Roegen and K. Boulding, Daly identifies two issues: (1) the growth model for Solow–Hartwick's sustainability is inconsistent with the physical laws of nature and (2) the framework of Solow–Hartwick's sustainability completely ignores the macroeconomic scale.

First, let us examine the theoretical framework of thermodynamic economics upon which Daly relies. Thermodynamic economics was founded by N. Georgescu-Roegen and K. Boulding. Georgescu-Roegen (1971, 1979) emphasizes the second law of thermodynamics (the entropy law) in asserting that economic processes are an irreversible process of transformation from low entropy to high entropy, and if low entropy is not continually introduced, the system cannot survive (Georgescu-Roegen 1971, Japanese translation pp.363–364). Based on the second law of thermodynamics, he directs fundamental criticism at the economic growth models of Solow, Hartwick, Stiglitz and others.

The other founder of thermodynamic economics, K. Boulding, presented the concept of the 'spaceman economy' (Boulding 1966, 1968). By invoking the first law of thermodynamics, Boulding advanced a transition from a linear system, where only production and consumption are captured as economic processes, to a circular system, where waste generated from the production and consumption processes, and partially recycled input of resources are included in economic processes (Pearce and Turner 1990, p.37). In the 'spaceman economy', throughput is recognized as something to be minimized, and in step with technological change, maintenance of total capital stock through less throughput (less production and consumption) becomes the objective of policy making (Boulding 1968 , pp.281–282). While Boulding made use of the concepts of a (closed) spaceman economy and throughput, his intent was to direct a warning at economic systems that unconditionally worship GNP growth. In other words, GNP growth is supported by a mass production- and mass consumption-based economic system that requires enormous material and energy inputs (throughput increase) to be viable; according to Boulding, such an economic system would definitely consume the environmental assets of future generations. GNP increase means throughput increase, which in turn means the breakdown of environmental assets, and thus, the shifting of burden to future generations. Such a perspective becomes clearer when considering the economy as a closed system. From an awareness of the above problems, Boulding posed the concept of the 'spaceman economy' and appealed to the need to move away from a 'cowboy economy'. While Boulding himself did not use the term SD, his viewpoint is clearly that of the SD perspective.

In addition to bringing a material cycle perspective to economic processes, N. Georgescu-Roegen and K. Boulding's succeeded in clarifying that the requirements for economic processes to survive as systems include not only the resource stocks, which are the source of low entropy but also the assimilative capacity of the environment, which makes up the dumping ground for high entropy. Daly has developed his theory of SD upon the abovementioned theoretical framework of thermodynamic economics.

3.2.1. Recognition of SD

Daly has defined SD as follows:

> 'The idea of "sustainable development" is development without growth, i.e. qualitative improvement in the ability to satisfy wants (needs and desires) without a quantitative increase in throughput beyond environmental carrying capacity.' (Daly and Farley 2004, p.6)

Daly has followed Georgescu-Roegen (1975, p.363) in distinguishing 'growth' from 'development' and viewed 'growth' as the physical increase in the throughput of material and energy in an economy, and 'development' as a fixed qualitative improvement in throughput (Daly1996, p.69).

$$\frac{B_{K_M}}{T} = \frac{B_{K_M}}{K_M} \times \frac{K_M}{T} \tag{11}$$

where K_M is manufactured capital, B_{K_M} is a benefit (or service) from manufactured capital and T is throughput. In equation (11), economic growth is seen as increasing T, and economic development is seen as increasing B_{K_M} per level of throughput at a fixed T[11], i.e.

$$economy\ is\ growing\ \text{ if } \frac{dT}{dt} > 0. \tag{12}$$

$$economy\ is\ steady\ state\ \text{ if } \frac{dB_{K_M}}{dt} > 0\ and\ \frac{dT}{dt} = 0 \tag{13}$$

Daly recognizes SD as an issue of transition from economic growth to a steady-state economy (Daly 1996, p.69).

3.2.2. Conditions for SD

Why does Daly so thoroughly criticize economic growth that increases throughput? The answer lies in the awareness of the issue that underlies Daly's theory of SD as per the citation below:

> '[I]f we choose to expand the economy, the most important natural space or

[11] "The throughput is the inevitable cost of maintaining the stocks of people and artifacts and should be minimized subject to the maintenance of a chosen level of stocks. The services (want satisfaction) yielded by the stocks of artifacts (and people) are the ultimate benefit of economic activity, and throughput is the ultimate cost" (Daly 1974, p.15).

function sacrificed as a result of that expansion is the opportunity cost. The point is that growth has a cost. It is not free, as it would be if we were expanding into a void. The Earth-ecosystem is not a void, it is our sustaining, life-supporting envelope. …[However,] [i]n macroeconomics, curiously, there is no 'when to stop rule', nor any concept of the optimal scale of the macroeconomy. The default rule is 'grow forever'. …When does the cost to all of us of displacing the Earth's ecosystems begin to exceed the value of the extra wealth produced?' (Daly and Farley 2004, pp.16–20)

To summarize Daly's awareness of the issue, it is impossible for an economic system of mass production and mass consumption to continue economic growth without limit for two reasons. One, the macroeconomy cannot grow beyond the physical limit of scale (sustainable scale). Daly assumes, without providing concrete evidence, that crossing the depletion threshold of resource stocks that are the source of low entropy and of the assimilative capacity, i.e. the dumping ground for high entropy, will cause ecological catastrophe or ecological disaster and infinite loss of utility (Daly and Farley 2004, p.21).

$$\text{if } K_N < K_N^* \text{ or } F_C < F_C^*, \text{ then } \frac{\partial U(T)}{\partial T} \to -\infty \quad (14)$$
$$\text{such that } T = -\Delta K_N - \Delta K_M = -\Delta F_C$$

where K_N is the resource stock, F_C is the assimilative capacity, K_M is the manufactured capital, K_N^* and F_C^* are the threshold (or critical level) of K_N and F_C, respectively, and T is throughput. $U(\cdot)$ is an aggregated utility function. Therefore, achieving a sustainable scale requires not exceeding the thresholds of resource stocks and assimilative capacity.

$$\text{Macroeconomy scale is } \textit{sustainable} \text{ if } K_N \geq K_N^* \textit{ and } F_C \geq F_C^* \quad (15)$$

Incidentally, the concept of throughput involves the problem of not always appropriately expressing the changes in resource stocks and assimilative capacity. Throughput is a flow concept and can be considered as the accumulation of man-made capital subtracted from the depletion of resource stocks (Daly 1996, p.111). However, in the end, throughput is an expression of the volume of physical material that becomes waste, and an increase or a decrease in throughput does not necessarily and directly increase or decrease resource stocks or assimilative capacity. As clarified by $T = -\Delta K_N - \Delta K_M = -\Delta F_C$ in equation (14), even if the volume of depletion of resource stocks in a given period ($-\Delta K_N$) is large, if accumulation of man-made capital (ΔK_M) is made sufficiently large, the volume of waste in that period ($-\Delta F_C$) will be small, and conversely, even if the volume of depletion of resource stocks in a given period is small, if there is almost no accumulation of man-made capital, the volume of waste in the period will be large. Therefore, even if throughput is fixed, how it will change the values of

ΔK_N and ΔF_C cannot be understood from the concept of throughput itself. In order to investigate changes in the values of ΔK_N and ΔF_C, merely looking at the total volume of the physical volume called throughput is insufficient; the paths and time spans through which material and energy flow in economic processes is important. In a sense, this indicates the limitations of the material volume called throughput as an indicator. Connecting the conditions of equation (15) with the concept of throughput requires clarifying the ways in which material and energy flow. However, Daly considers an increase in throughput as simply increases in the values of ΔK_N or ΔF_C, a point that calls for caution.

Another reason is economic limits, because of which economic growth itself ceases to bring benefits when the optimal scale of macroeconomic growth is surpassed. In Daly's theoretical framework, the macroeconomic optimal scale is set at a point where the marginal social benefits derived from the accumulation of man-made capital and the marginal social cost resulting from the depletion of natural capital (the opportunity cost of goods and services derived from natural capital) are balanced (Daly and Farley 2004, p.21).

$$\text{Macroeconomy scale is } \mathit{optimal} \text{ if } \frac{\partial B(K_M)}{\partial K_M} = \frac{\partial C(K_N)}{\partial K_N} \qquad (16)$$

where $B(K_M)$ is a marginal social benefit from accumulating manufactured capital and $C(K_N)$ is a marginal social cost from depleting natural capital.

Here the following points are vital. First, the conditions in (15) and (16) are assumptions and not drawn from the theoretical framework of thermodynamic economics. Second, as made clear by the conditions of (16), Daly's theory of optimal scale rests upon the neoclassical economics theoretical frameworks that Daly so thoroughly criticized, and presumes economic valuation of natural capital. However, Daly does not develop the argument for that methodology at all, nor does he present an original methodology. Third, the relationship between the conditions of (15) and (16) and the throughput concept is not clear. Fulfilling the conditions of (15) and (16) does not necessarily decrease throughput, and the question of whether decreasing throughput leads the macroeconomy to a path of satisfying the conditions of (15) and (16) is not given theoretical consideration.

3.2.3. The positioning of natural capital

Natural capital is positioned as follows in Daly's theoretical framework. First, both man-made and natural capital are positioned as sources of welfare, as if capital itself supplies various goods and services and yields utility (Daly and Farley 2004, pp.17–18).

'We define capital as a stock that yields a flow of goods and services into the future. Stocks of man-made capital include our bodies and minds, the artifacts we create and our social structures. Natural capital is a stock that yields a flow of natural services and tangible natural resources. This includes solar energy, land, minerals and fossil fuels, water, living organisms and the services provided by the interactions of all of these elements in ecological systems'. (Daly and Farley 2004, p.17)

Second, in Daly's definition, natural capital is not the economic concept of production inputs, rather it is the physical concept of physical resource stocks, and strictly speaking indicates the physical stocks of low-entropy resources that are input into economic processes. A particular point to note is that assimilative capacity is not considered as natural capital in Daly's theoretical framework (Daly and Farley 2004, pp.107–109). However, Daly does not make it clear why only the resource stocks as the source of low entropy are included in natural capital, while assimilative capacity as the dumping ground for high entropy is not. How does Daly's concept of natural capital, with its features as outlined above, relate to the conditions for SD? Next, we will consider how to interpret, through the concept of natural capital, Daly's operational principles (below), envisioned by Daly as policy guidelines towards achieving SD (Daly 1991, p.45; Daly 1995, p.50), and consider what theoretical foundation underlies these principles.

1. The main principle is to limit the human scale (throughput) to a level, which if not optimal, is at least within carrying capacity, and therefore, sustainable.
2. Technological progress for sustainable development should be efficiency-increasing rather than throughput-increasing.
3. [For renewable resources] (a) harvesting rates should not exceed regeneration rates and (b) waste emissions should not exceed the renewable assimilative capacity of the environment.
4. Non-renewable resources should be exploited, but at a rate equal to the creation of renewable substitutes.

The first and second operational principles are related to equations (15) and (13), respectively, i.e.

$$K_N \geq K_N^* \ \ and \ \ F_C \geq F_C^* \tag{17}$$

$$\frac{dB_{K_M}}{dt} > 0 \ \ and \ \ \frac{dT}{dt} = 0 \tag{18}$$

where K_N is resource stock, F_C is assimilative capacity, K_N^* and F_C^* is threshold (or critical level) of K_N and F_C, respectively, B_{K_M} is a benefit from manufactured capital (K_M) and T is throughput, which can be defined as $T = -\Delta K_N - \Delta K_M = -\Delta F_C$.

In addition, the third and fourth operational principles display the conditions below:

$$\frac{dK_{NR}}{dt} \geq 0, \qquad \frac{dF_C}{dt} \geq 0 \tag{19}$$

$$-\frac{dK_{NN}}{dt} + \frac{dK_{NR}}{dt} \geq 0 \tag{20}$$

where K_{NN} is a non-renewable resource stock, K_{NR} is renewable resource stock and F_C is an assimilative capacity.

As already noted, equation (17) is not so much drawn from the theoretical framework of thermodynamic economics as it is positioned as rather a common-sense assumption. Formulas (19) and (20) are presented on three grounds: the concept of 'sustainable income', the 'complementarity' of natural capital and the assumption of 'full world' macroeconomics (see Daly 1996, chapter 4). The first of these, 'sustainable income', is the 'Hicksian definition of income' and means 'that the level of income that a nation can afford to consume without running down its overall capital stock' (Pearce et al. 1993, p.32)[12]. By adopting the concept of 'sustainable income', Daly treats the idea of maintaining capital intact as a foundation. The second item, the 'complementarity' of natural capital, places man-made and natural capital in a relationship as complements rather than substitutes, and is Daly's original assertion (Daly 1991, pp.25–26). As his rationale, Daly looks separately at the physical, historical and philosophical aspects. With regard to the physical aspects, he draws upon the theoretical framework of thermodynamic economics to strongly criticize the view of a perfectly substitutable relationship between man-made and natural capital as incompatible with physical law. This is based upon the recognition of physical non-substitutability of natural capital under the law of thermodynamics[13]. With regard to historical aspects, he develops the argument that while economies do deplete natural capital to accumulate man-made capital, if man-made capital is a near-perfect substitute for natural capital, then

[12] J. Hicks defined income as 'the maximum amount that a community can consume over some time period and still be as well off at the end of the period as at the beginning' (Hicks 1946 quoted in Daly 1996, p.75).

[13] However, regarding the relationship between low entropy resources and absolute scarcity, two doubts arise. One is that it is not supported by empirical research on the R or P ratio of non-renewable resources (Neumayer 2003). Neumayer (2003) compared the world oil reserves or production ratio in 1965 and 2001, and the world natural gas reserves or production ratio in 1970 and 2001, finding that 2001 had a higher value than 1965 (oil) and 1970 (gas), and that for coal, gas, oil, mercury, iron and aluminum, remaining capacity had increased in 2001 over 1970 (Neumayer 2003, pp.116–118). The other issue is that the limitedness of low entropy resource stocks can be mitigated by solar energy (Sagoff 1995, p.612). For example, 'the spontaneous flow of energy on earth from low- to high-entropy states may be offset by solar flow… With the availability of outside energy, materials on earth may be reorganized and restored to a useful state' (Townsend 1992, p.98), and even Georgescu-Roegen recognized that it might be possible 'to make greater use of solar radiation, the more abundant source of free energy [i.e. low entropy]' (Georgescu-Roegen 1973). Despite these problems being raised, Daly has not altered his stance on the absolute limitedness of low entropy resources, without clarifying the rationale for such.

natural capital must also be a near-perfect substitute for man-made capital, and there is no reason to promote the accumulation of man-made capital; this, he argues, clearly illustrates that man-made and natural capital are complements. With regard to philosophical aspects, he draws upon the material cause and the efficient cause from Aristotle's four causes that explain all things and asserts: 'One cannot substitute efficient cause for material cause—one cannot build the same wooden house with half the timber no matter how many saws and carpenters one tries to substitute. Also, to process more timber into more wooden houses, in the same time period, requires more saws, and carpenters' (Daly 1991, p.26).

Combining the above 'sustainable income' concept with the 'complementarity' of natural capital leads to the idea of 'maintaining natural capital intact'. This is the theoretical underpinning behind Daly's equations (19) and (20), but some have claimed that the idea of the 'complementarity' of natural capital ignores economic definitions. As Beckerman (1995) and Stiglitz (1997, p.267) point out, Daly does not use the terms 'substitutes' and 'complements' in the proper economics sense. In the Slutsky equation of consumer theory, if the sign of the substitution term (partial differential of compensated demand function) $s_{ij} = \partial x_i^* / \partial p_j$ (x_i^*: demand for i goods, p_j: price of j goods) is positive (negative), then i goods are defined as substitutes (complements) for j goods (Nishimura 1990, pp.69–70). As made explicit by this definition, when the price of j goods increases, if demand for i goods increases then i goods are called substitutes for j goods, and conversely, if demand for i goods falls then i goods are called complements of j goods. Strictly speaking, substitutes and complements are a concept for making the relationship between price changes and demand changes explicit with the goal of maintaining a fixed level of consumer utility, and are not intended for debating the substitutability of capital in the production function. If substitutability in the production function is to be debated, then elasticity of substitution must be used; however, that too is not a concept for debating the physical substitutability of capital. Daly ignores the definition of the concept in economics when developing his argument of non-substitutability. D. Pearce and K. Turner criticize Daly for building total substitutability or complementarity of natural capital into his argument, and state the need to debate substitutability through empirical research (e.g. Pearce 1997, p.296; Turner 1997, p.300). Daly's assertion of natural capital as a complement comes from his intent to explain how economic development is first achieved when both man-made capital and natural capital exist, which was itself an important point; however, arguing complementarity while ignoring its definition in economics led Daly to lose rigorousness in his own SD theory.

Equation (18) asserts that technological progress is necessary to increase the benefits derived from man-made capital without increasing throughput, whereas the other three conditions related to the goals of SD, equation (18) is a condition related to the means for achieving those goals[14]. In Daly's theoretical framework, with natural capital positioned as stocks of low-entropy resources, what humans can do is limited to 'waiting or refraining from current consumption' (Daly 1994, p.29), which is interpreted as investment in natural capital.

3.3. Ekins' sustainability

3.3.1. Recognition of SD

P. Ekins, while making the sustaining of human welfare the goal of SD, divides SD into environmental, economic, social and ethical dimensions, proposing that sustainability should be achieved in each of these dimensions (Ekins 2000, pp.104–106). For example, environmental sustainability is achieved through the maintenance of important environmental functions, and economic sustainability is achieved through maintenance or increase of the capital stock composed of natural capital, manufactured capital, human capital and social capital (Ekins 2000, pp.104–105). Therefore, the goal of SD is expressed as follows:

$$\frac{dW^{Env}}{dt} \geq 0 \ and \ \frac{dW^{Econ}}{dt} \geq 0 \ and \ \frac{dW^{Soc}}{dt} \geq 0 \ and \ \frac{dW^{Eth}}{dt} \geq 0 \qquad (21),$$

where W^{Env}, W^{Econ}, W^{Soc} and W^{Eth} are each a dimension of welfare and cannot be summed.

The reason why Ekins considers the goals of SD taken apart into individual dimensions per equation (21) lies in the assumption of 'the incommensurability of the

[14] Daly expresses the efficiency of the use of natural capital more generally as the following identity equation:

$$\frac{G_{K_M}}{L_{K_N}} = \frac{G_{K_M}}{K_M} \times \frac{K_M}{T} \times \frac{T}{K_N} \times \frac{K_N}{L_{K_N}}$$

where K_M is man-made capital stock, K_N is natural capital stock, G_{K_M} is a gain from the service from K_M, L_{K_N} is a loss of the services of K_N and T is a throughput which is the total material flow in the macro-economy, defined as 'the flow of natural resources from the environment, through the economy, and back to the environment as waste' (Daly and Farley 2004, p.6). The first item on the right side of the identity equation represents the benefit derived per unit of man-made capital (service efficiency), the second item represents man-made capital stock derived per unit of material and energy (throughput) input into the economy (maintenance efficiency) and the third item represents the size of throughput per unit of natural capital (growth efficiency). The fourth item represents the natural capital stock sacrificed per unit of natural capital service (ecosystem service efficiency). Maximizing the efficiency of use of natural capital broken down into these elements is what Daly seeks.

constituents of human welfare' in Ekins' theory of SD. In his theory of SD, human welfare is composed of various elements, and the 'search for a single, aggregate measure of human welfare was unlikely to be fruitful, and that a number of measures giving insight into different aspects of welfare would be more likely to convey the complex realities involved' (Ekins 2000, p.104). What must be noted here is that the term 'human welfare' as used by Ekins is not the social welfare of economics, rather it is used in the meaning of human happiness or well-being. Ekins asserts that the elements composing human happiness or well-being are multi-dimensional, with attempts at their evaluation as a single measurement 'unlikely to be fruitful'. The characteristic of Ekins theory of SD is its previously noted elaboration of 'the incommensurability of the constituents of human welfare', and its assumption that natural capital makes a unique contribution to welfare.

3.3.2. Conditions for SD

Ekins positions environmental sustainability as a necessary condition for SD (Ekins 2000, pp.76–77). Ekins (2000) defines environmental sustainability as the maintenance of important environmental functions. 'Environmental functions' here have been divided by various commentators into several categories; according to Ekins these are source, sink, life-support and amenity[15] (Ekins 2003a, b; Ekins et al. 2003). A particular characteristic of Ekins' sustainability is the distinction between 'Functions for' humans and 'Functions of' the environment, with the environmental functions coming under 'Functions for' (source, sink and amenity functions) made possible by the performance of the environmental function coming under 'Functions of' (life-support function), he asserts (Ekins et al. 2003).

Incidentally, is 'environmental functions' a flow concept or a stock concept?

> 'Where the stocks of capital, which perform these functions, cannot be substituted by other stocks of environmental or other capital, which perform the same functions, they may be called critical natural capital' (Ekins et al. 2003, p.174).

From this, we see that Ekins positions environmental functions as the flow of services derived from natural capital stocks[16] (see also Ekins 2000, pp.104–108). Natural capital

[15] The idea of environmental functions originate with Hueting (1974) and De Groot (1992). The categories Environmental functions, Regulation, Production, Habitat and Information (see De Groot et al. 2003, Chiesura and De Groot 2003), and the categories Source, Sink, Life-support, Scenery and Site (Noel and O'Connor 1998) have been proposed.

[16] The following definition also exists for environmental functions: 'the capacity of natural processes and components to provide goods and services that satisfy human needs' (De Groot 1992, Noel and O'Connor 1998, p.75). From this definition, environmental functions can be considered as a stock concept. While the viewing of environmental functions as a unique physical property is consistent, the

stocks provide flows of services categorized as source, sink, life-support and amenity. If among these services, there are any judged to possess the properties of non-substitutability and irreversible or immoderate loss, such services are deemed critical environmental functions (Ekins et al. 2003, p.173). In Ekins sustainability, maintaining these critical environmental functions is a necessary condition for achieving environmental sustainability, i.e.

$$EF \geq EF^{*} \qquad (22),$$

where EF is critical environmental functions (source, sink, life-support and amenity) and EF^{*} is the critical level of EF.

Ekins defines the natural capital stocks that generate the flow of these critical environmental functions as CNC.

> 'Critical natural capital (CNC) is the natural capital that enables such functions to be performed, with the additional condition that, for any particular CNC, and resulting environmental function, there is no substitute type of capital, natural or man-made, which would enable the same function to be performed to the same extent, i.e. CNC is non-substitutable in respect of the function in question' (Ekins 2003b, p.277).

Then why does Ekins make preservation of critical environmental functions as a flow (per equation (22)), not conservation of CNC as a stock, the requirement for environmental sustainability? Just as water resources in the water cycle have multi-faceted characteristics such as water reservoirs, water quality, interactions with the atmosphere and runoff, natural capital is positioned as a composite with many physical characteristics (Ekins and Simon 2003). What makes environmental functions work is essentially the physical characteristics of natural capital, and thus, that should be the target of preservation (Ekins 2003b, p.278); this is the basic standpoint of Ekins' theory of SD. However, such physical characteristics, if in some cases inherent in given natural capital, are also in some cases born of interaction among natural capital. If natural capital and the physical characteristics behind some critical environmental function have a one-to-one correspondence, that may be specified as CNC. However, environmental functions work as the result of interaction among various physical characteristics straddling different kinds of natural capital, making it difficult to specify CNC as a unique natural capital (Ekins 2003b, p.278; Ekins and Simon 2003, p.256). Thus, Ekins theory of SD emphasises environmental functions as the product of natural capital interaction and networks, and theoretically draws out the need to preserve

distinction between stock and flow is not rigorously made. While this is a general problem with such environmental functions, Ekins at least grasps natural capital and environmental functions as relationships between stocks and flows.

ecological systems as it is.

From the above, Ekins gives up on specifying CNC, instead thoroughly gathering information on the economic activities that impinge on the physical characteristics of natural capital, and advancing his discussion along the direction of specifying how distanced critical environmental functions are from sustainable levels.

How can the sustainable level of critical environmental functions be concretely determined? On this point, while basing discussion upon the safe minimum standard (Ciriacy-Wantrup 1952), Ekins interprets critical zones (or critical load) as the threshold of environmental functions, and thus, sets the preservation level for environmental functions (see Ekins et al. 2003b).

> 'In the context of complex systems, the critical zone can be thought of as the threshold, the passing of which may flip an ecosystem into another stability domain. Avoiding exceeding the threshold implies that management must build buffer capacity or resilience' (Ekins et al. 2003, p.174).

Thus, in order to determine how distanced critical environmental functions are from sustainable levels, the critical zones of environmental functions must be made explicit. However, these critical zones cannot be determined purely through scientific point of view, and rather accompany political and moral judgments (Neumayer 2003, p.194). Therefore, the Ekins theory of SD, with its emphasis on environmental sustainability, ultimately faces the major issue of determining these critical zones.

3.3.3. Positioning of natural capital

A required condition to achieve environmental sustainability in the Ekins' theory of SD is the maintenance and preservation of the critical environmental function. Such a natural capital that provides critical environmental functions is positioned as CNC; however, what is important for Ekins is the physical characteristics possessed by natural capital or CNC, with the stocks of natural capital or CNC not the direct target of preservation. The originality of the Ekins' theory of SD lies in its considering the critical environmental functions as the product of interaction of natural capital or networks; Ekins also raises the important issue that simply preserving individual stocks of natural capital may not ensure the achievement of environmental sustainability. Moving this idea forward, preservation without loss of the totality of ecological systems is called for; however, given that the response to the question of 'what is to be preserved' might be 'all natural capital', and given the difficulty of determining the critical zones of critical environmental functions, applying the ideas to practical policy is accompanied by difficulties.

3.4. Pearce–Turner's sustainability

3.4.1. Recognition of SD

As the root premise behind their theory of SD, Pearce and Turner (1990) employ a circular economy model derived from the law of thermodynamics. Daly's sustainability also adopted the circular economy as its premise, whereas Daly tended to focus on resource stocks and assimilative capacity (the physical conditions for sustainable functioning of economic processes), Pearce–Turner, while picking up that perspective of Daly's, additionally position aesthetic commodity (amenity service) as the economic function of the environment that has a direct impact on the utility of individuals in the circular economy (Pearce and Turner 1990, pp.40–42). Pearce–Turner sympathise with the awareness of issues in Daly's sustainability, but take their theoretical framework from Solow–Hartwick's sustainability.

However, they do not take the model of optimal depletion of non-renewable resources as it is from Solow–Hartwick's sustainability. The framework of Solow–Hartwick's sustainability was expanded to cover renewable resources (see Hartwick 1978b, 1994; Solow 1986; Maler 1991). What was thus clarified was that when renewable resources input, not non-renewable resources one, are introduced into production process as natural capital, then consumption levels are determined by the magnitude relation between the rate of return holding the resource (the marginal productivity of capital) and the social discount rate[17] (Dasgupta and Heal 1979; Pearce 1998, p.73). It has become clear that when making renewable resources production inputs, the path to optimal growth is consistent with the condition of non-declining or constant consumption when the rate of return holding the resource is greater than or equal to the social discount rate (Dasgupta and Heal 1979; Pearce 1998, p.73).

Based on Solow (1986), Maler (1991, p.12) presented maintenance of total capital stocks over time as a condition for SD, i.e.

$$\frac{d\boldsymbol{K}}{dt} = p_m \frac{dK_M}{dt} + p_n \frac{dK_N}{dt} \geq 0 \quad \forall t \qquad (23),$$

where $\boldsymbol{K}$ is total capital stock, K_M is man-made (reproducible) capital, K_N is natural capital and p_m and p_n are accounting prices of man-made and natural capital, respectively[18].

---

[17] Setting the rate of return holding the resource as r and the discount rate as s, when r > s consumption increases, when r = s consumption is level and when r < s consumption decreases.

[18] Human capital is included in man-made capital for simplicity. As human capital is also valued in monetary terms, it is possible to include it in man-made capital.

Equation (23) indicates maintenance of the economy's productive base over time. While Pearce–Turner's theory of SD presumes the circular economy model, its goal of SD is 'that per capita utility or well-being is increasing over time' (Pearce et al. 1989, p.33), with the 'constant capital rule' (equation (23)) positioned as a condition to achieve intergenerational equity (Pearce et al. 1994, p.463).

> 'Sustainable development in these broader terms involves providing a bequest to the next generation of an amount and quality of wealth that is at least equal to that inherited by the current generation. It can be shown that such a "constant capital" bequest is consistent with the concept of intergenerational equity. Sustainable development is therefore partly about intergenerational equity' (Pearce et al. 1989, p.48).

3.4.2. Conditions for SD

Pearce–Turner place the idea of constant capital, with in the studies by Solow (1986) and Maler (1991, pp.11–12) as the foundation for their theory of SD.

To empirically analyze the constant capital rule, Pearce and Atkinson (1993) present the savings rule as follows[19]:

$$\mathrm{Z} \geq 0 \quad \text{if} \quad S \geq \delta_M + \delta_N \qquad (24),$$

where S is saving rate, Z is sustainability index, δ_M is depreciation rate of manufactured capital and δ_N is depreciation rate of natural capital. The condition for equation (24) indicates a required condition to make wealth non-declining. More concretely, it shows that by consuming within a range that does not make the savings rate smaller than the depreciation rate of man-made capital and natural capital, it is possible to take an optimal path to maximizing welfare while maintaining the condition of non-declining wealth.

Equation (24) takes up the theoretical framework of Solow–Hartwick's sustainability,

---

[19] Following Perman et al. (1999, p.512), equation (24) is derived as follows. Where W is wealth, Y is income, C is consumption and D is depreciation of the asset portfolio, change in wealth can be expressed as $W_t - W_{t-1} = Y_t - C_t - D_t$. Under the constraint condition of constant capital rule ($W_t - W_{t-1} = 0$), when maximizing welfare, $Y_t - C_{max,t} - D_t = 0$ ($C_{max,t}$ is the maximum level of consumption subject to $W_t - W_{t-1} = 0$). By definition, $C_{max,t}$ can be interpreted as sustainable income. Thus, expressing $Y_{sus,t}$ as sustainable income, we derive $Y_t - C_{max,t} - D_t = 0 \leftrightarrow Y_{sus,t} = Y_t - D_t \leftrightarrow Y_{sus,t} - C_t = S_t - D_t$ ($\because Y_t = C_t + S_t$ where S_t is savings). Thus, from $Y_{sus,t} - C_t = S_t - D_t$, the conditions below are derived:

$$Y_{sus,t} - C_t < 0 \leftrightarrow S_t - D_t < 0 \leftrightarrow W_t - W_{t-1} < 0$$

$$Y_{sus,t} - C_t = 0 \leftrightarrow S_t - D_t = 0 \leftrightarrow W_t - W_{t-1} = 0$$

$$Y_{sus,t} - C_t > 0 \leftrightarrow S_t - D_t > 0 \leftrightarrow W_t - W_{t-1} > 0$$

To set $W_t - W_{t-1} \geq 0$, $S_t - D_t \geq 0$ is sufficient. If D_t is decomposed as depreciation of man-made capital and natural capital, the condition equation (24) is derived.

with Hartwick's rule as a theoretical pillar. However, with regard to the physical aspects of Hartwick's rule, Pearce–Turner recognize that the natural environment has distinctive features not found in man-made capital, the multi-functionality of natural resources and environment, life-support function, irreversibility, unknown scale of effects from loss, loss aversion, and that substitutability of man-made capital and natural capital does not always hold true as per the assumptions of the Hartwick's rule (Pearce 1998, pp.84-85, Pearce and Turner 1990, p.49). With the circular economy model as its foundation, Pearce–Turner's sustainability takes issue with assimilative capacity, amenity service, life-support function and other distinctive features of the natural environment being largely abstracted within Hartwick's rule (Pearce and Turner 1990). This is an awareness of issues shared with the theories of SD of Ekins and Daly. Pearce–Turner intended to resolve the inconsistency between Hartwick's rule and the circular economy (thermodynamic law) by 'introducing an upper bound on the assimilative capacity assumption, as well as a lower bound on the level of K_N stocks necessary to support SD assumption' (Turner 1993, p.11), and stated that 'a "constant natural capital" rule…should include biodiversity and the basic biogeochemical cycles that support life' (Pearce1998, p.85). Pearce–Turner conceptualized natural capital possessing such distinctive features as CNC, and fully recognized the importance of preserving it in a category separate from total capital stocks.

The constant natural capital rule requires not only the maintenance of total capital stocks measured as economic value under Hartwick's rule but also in terms of economic value or physical dimensions of natural capital, preservation of natural capital itself (Pearce and Turner 1990, p.53; Pearce et al. 1993, p.64). The constant natural capital rule is expressed as follows (Turner 1993, p.10):

$$\frac{\partial K_N}{\partial t} \geq 0 \quad \forall t \quad \text{or} \quad \delta_N \leq 0 \tag{25}$$

Pearce–Turner considered two directions for applying equation (25)'s constant natural capital rule: to natural capital stocks overall and to a portion of critical natural assets stocks (see Pearce 1998, pp.98–100; Turner 1993, p.10).

Based on this, Pearce–Turner present both a constant capital rule and a constant natural capital rule. However, characteristic of Pearce–Turner's framework is its consideration of equation (24) as strictly a minimum necessary condition for SD (Pearce and Atkinson 1993; Pearce 1998; Perman 1999, p.512). In other words, while differences existed between Solow–Hartwick's sustainability and Daly's sustainability in the recognition of SD and the natural capital concept, Pearce–Turner recognizes that both of these can position equation (24) as a minimum requirement to be satisfied. Moreover, as equation (25) can be calculated from the information required to calculate equation (24), the informational basis required by both Solow–Hartwick's sustainability and Daly's sustainability are the same, and in the end, lead to the evaluation problem of the depletion of natural capital (Pearce 1998, p.98). If, with equation (24) positioned as a minimum necessary condition, natural capital to be preserved—the target for application of equation (25)—can be determined based on some theoretical rationale, then the conflict between Solow–Hartwick's sustainability and Daly's sustainability becomes a non-issue. The CNC concept is positioned as natural capital required to satisfy equation (25).

3.4.3. Positioning of natural capital

From the above, Pearce–Turner interpret natural capital in two ways. One, the natural resources or environment that are the target for application of equation (24), as production inputs substitutable with man-made capital. The other is the natural resources or environment that are the target for application of equation (25), possessing distinctive features such as life-support function, amenity service and assimilative capacity, and which thus cannot be substituted with man-made capital. Pearce–Turner conceptualized this as CNC. Equation (24) is a common requirement to be satisfied by both Solow–Hartwick's sustainability and Daly's sustainability, the satisfying of which allows consumption that maximizes welfare without reducing wealth, and also secures intergenerational equity. Pearce–Turner, while relying on the capital theories of Solow (1986) and Maler (1991), take Solow–Hartwick's sustainability and Daly's sustainability non-exclusively, and rather position the constant capital rule as a first step in advancing constructive dialogue among the two (cf. Beckerman 1995; Daly 1995).

> 'A strong sustainability indicator would evolve identifying and measuring "critical" natural capital such that any positive depreciation would be a sign of non-sustainability. …we believe that natural capital measurement may not be able to capture all the economic functions of ecological systems. But we argue strongly that efforts to monetize the values of those functions advances the development of an ecologically based economics' (Pearce and Atkinson 1993, p.106).

Whereas Daly presupposed low-entropy resources alone as natural capital, Pearce–Turner's concept of natural capital encompasses resource stocks, assimilative capacity, amenity services and life-support services. In particular, it positions the natural resources or environments that provide life-support services as CNC.

4. Discussion

In the previous section, we categorized discussions of SD into four approaches to sustainability and examined the theoretical framework of each. In this section, we clarify the theoretical relationships between each approach to sustainability and concepts of natural capital and consider the positioning of the CNC concept therein.

4.1. Natural capital and four approaches to sustainability

In the first case, Solow–Hartwick's sustainability, natural capital is treated primarily as a stock of production inputs. This is basically because the Solow–Hartwick's theoretical framework considers a utility function with consumer goods as a variable, and interprets SD as the optimal growth path that realizes constant or non-declining consumption. With natural capital positioned strictly as a production input, the concept of natural capital is treated as substitutable with man-made capital. As noted, this point was severely criticized by Georgescu-Roegen and Daly.

In the second case, Daly's sustainability, the physical laws abstracted by Solow–Hartwick's sustainability are emphasized, and natural capital is positioned exclusively as stocks of low-entropy resources. Daly criticizes Solow–Hartwick's sustainability as completely ignoring physical laws. Daly sees economic processes as processes of increasing entropy, and considers the low-entropy resources needed to avoid high entropic state in economic processes, as well as the assimilative capacity that is the dumping ground for waste, as absolute necessities. Premised on that recognition, in Daly's sustainability, low-entropy resource stocks are positioned as natural capital. As clarified by Daly's definition, natural capital is used more to mean physical stocks rather than production inputs, but we must note that assimilative capacity is not thought of as natural capital. Either way, as man-made capital is created from low-entropy resources, the stock of which is natural capital, man-made capital cannot be substituted with natural capital. In this way, natural capital is *a priori* recognized as non-substitutable with man-made capital in Daly's sustainability.

In the third case, Ekins' sustainability, natural capital is positioned as a stock with four environmental functions categorized as source, sink, life-support, and amenity. In particular, environmental functions judged as possessing the characteristics of non-substitutability and irreversible/immoderate loss are deemed critical environmental functions, whose maintenance over time is a requisite for SD. However, for Ekins, physical characteristics are the essential factors behind critical environmental functions, and natural capital possessing such physical characteristics is particularly seen as CNC. Some physical characteristics are inherent in a specific CNC, and others are also generated through the interaction among different kinds of CNC. Given the complexity of ecosystems, natural capital interaction and network structure may be difficult to fully understand, and thus, to preserve physical characteristics, the preservation of ecological systems itself is necessary. Although Ekins' sustainability uses the term natural capital, its meaning is stocks that possess or exhibit physical characteristics. But given preservation of ecological systems as the intent, all constituents of ecological systems may be treated as natural capital.

In the fourth case, Pearce–Turner's sustainability, natural capital is recognized in two ways. One is as resource stocks that provide resource flows, the same as the traditional natural capital concept found in Solow–Hartwick's sustainability. The other is as environmental stocks that provide waste sink, amenity service and life-support functions. While the waste sink and life-support functions in the latter appeared in the awareness of issues in Daly's sustainability, these were not treated as natural capital, but here are included in the natural capital concept. Moreover, amenity service was not given any importance in Daly's sustainability, but this too is included in Pearce–Turner's concept of natural capital as a vital service of the environment. In the latter sense, within natural capital, environmental stocks that provide the life-support function are specifically called CNC by Pearce–Turner. While Pearce–Turner adopt the theoretical framework of Solow–Hartwick's sustainability, they take an interest in the distinctive features of natural resources and environment that get abstracted in the capital theory; this provides the reason behind their above categorization of natural capital. Still, Pearce–Turner do not side with the *a priori* non-substitutability of natural capital with man-made capital seen in Daly's sustainability:

> 'It is likely that both characterizations of reality [whether man-made capital can substitute natural capital or not] are false: it is difficult to see environment and development always as being in mutual harmony, and equally difficult to accept that environment always has to be sacrificed if we want economic progress. So far as either is true, the complementarity hypothesis is more correct for countries at an early stage of development, and the trade-off approach is more correct for countries in the later stages' (Pearce et al.1990, p.17).

Therefore, Pearce–Turner position the constant capital rule (equation (23)) as the requisite for SD that both Solow–Hartwick's sustainability and Daly's sustainability should minimally satisfy. Furthermore, the constant natural capital rule (equation (25)) should be applied according to social context, and should never be determined *a priori*.

On its surface, Pearce–Turner's concept of natural capital appears to fall under the same category as natural capital in Ekins' sustainability, but a difference lies in Pearce–Turner's stance of determining the substitutability of natural capital according to social context, and Ekins' stance of *a priori* assuming the substitutability of natural capital.

4.2. Critical natural capital and four approaches to sustainability

By clarifying the theoretical relationship between the natural capital concept and the four approaches to sustainability, we can consider the theoretical basis of the CNC concept. The CNC concept is strictly a capital concept, and cannot exceed the framework of natural capital. Therefore, the theoretical foundation of CNC depends on the theoretical foundation of natural capital.

How might CNC appear within each of the four approaches to sustainability?

In the first case, Solow–Hartwick's sustainability, as natural capital is treated as a stock of production inputs, CNC is limited to a production input. The issue is in what cases production inputs can be specified as CNC, and in Solow–Hartwick's sustainability, essential production inputs—i.e. those without which production becomes impossible—are interpreted as CNC. Naturally, the term CNC is not used in Solow–Hartwick's sustainability. Rather, it intends to clarify the conditions under which production inputs become non-essential, but in response to the SD question 'What is to be sustained?' the response 'production inputs without which production of consumer goods is impossible' can be derived, and this can be interpreted as CNC. Therefore, production inputs satisfying equations (6) and (9), essential resource conditions, are specified as CNC.

In the second case, Daly's sustainability, natural capital is treated as the stock of low-entropy resources. As the assimilative capacity of the environment is not included within the concept of natural capital, CNC is exclusively limited to low-entropy resources in economic processes. The issue is what low-entropy sources are to be interpreted as CNC, but from equation (14), natural capital possessing characteristics such that infinite loss of utility occurs when a given threshold is crossed ($K_N < K_N^*$) is interpreted as CNC in Daly's sustainability. As Daly supposes that all resource stocks possess such characteristics, then per Daly, all natural capital must be CNC (although he does not use the term CNC). For that reason, he may well not feel the particular need to differentiate natural capital from CNC. But how can the natural capital threshold beyond which ecological catastrophe occurs be determined? On this point, Daly only assumes that this natural capital threshold exists, and does not discuss procedures or methodology for its determination for practical purposes. As such, CNC cannot be concretely determined under Daly's sustainability. All that can be said is that under Daly's sustainability all natural capital may be CNC.

As Solow–Hartwick's sustainability and Daly's sustainability bring SD theory to the discussion of the limits of economic growth posed by Meadows (1972), especially in the point of the possibility of sustainable production of consumer goods, the CNC concept is limited to production inputs in both approaches to sustainability.

In the third case, Ekins' sustainability, and the fourth case, Pearce–Turner's sustainability, the natural capital concept itself is not limited to inputs in production processes, and thus, the CNC concept too has an accordingly wider range than merely that of inputs. Whereas Solow–Hartwick and Daly did not use the term CNC, Ekins and Pearce–Turner actually position the CNC concept as a requisite for SD. Ekins' sustainability positions CNC as stocks that perform critical environmental functions with the characteristics of non-substitutable and irreversible/immoderate loss; Pearce–Turner's sustainability positions CNC as stocks that provide life-support functions. While Ekins takes the stance that directly specifying CNC is impossible, he does designate environmental functions with a critical level (threshold) that generates immoderate cost as critical, and thus, based on Ekins' sustainability, all natural capital may become CNC. In contrast, Pearce–Turner limit CNC to life-support functions, thus treating the CNC concept within a more limited scope than that in Ekins' sustainability.

What can be called important here is that Pearce–Turner consider CNC related to uncertainty:

> '…the unknown scale of effects from loss of critical natural capital, particularly where thresholds are thought to be present—witness the divergent views about the effects of global warming' (Pearce 1998, p.85).

As suggested here, the problem of specifying CNC must be considered under the conditions of 'unknown scale of effects'; as a direction, Pearce (1998, p.85) proposes safe minimum standard (Ciriacy-Wantrup 1952). Even in Ekins' sustainability, when specifying the critical level (threshold) at which environmental functions cause immoderate cost, safe minimum standard is followed. Therefore, CNC in Ekins' sustainability and CNC in Pearce–Turner's sustainability face ultimately the same problem, that of specifying critical level under uncertainty. Until this problem is solved, critical environmental function in Ekins' sustainability cannot be determined, and the target for applying the 'constant natural capital rule' (equation (25)) in Pearce–Turner's sustainability cannot be determined.

In actuality, this problem is an extremely large one for Daly's sustainability as well. In Daly's sustainability, the important base for the preservation of natural capital seen in equation (14)—when low-entropy resource stocks are depleted below a certain threshold, infinite loss of utility occurs—is nothing more than an assumption of Daly's, and is not a verifiable result of theoretical deliberation. This can be seen as weakening the validity of Daly's criticism of Solow–Hartwick's sustainability. The matter of determining critical level (threshold) is essential for making Daly's assumption verifiable, and the procedures or methodology may serve to correct problems in the current theoretical framework of Daly's sustainability, which specifies all natural capital as CNC. If current levels of resource use are deemed to be pushing the critical level (threshold), the correctness of the theory of SD in Daly's sustainability will be demonstrated, and if not, then the correctness of the theory of SD in Solow–Hartwick's sustainability will be demonstrated. Both theories of SD have an interest in the sustainable production of consumer goods, but what is important is not which approaches to sustainability is *a priori* correct, but rather which the validity of the SD theory itself changes depending on the manner of recognizing and evaluating the critical level (threshold).

Table 1 Summary of the four approaches to sustainability

	Goal of SD	Conditions for SD	Positioning of natural capital	Definition of CNC
1) Solow–Hartwick	$dC_t/dt \geq 0$	$\sigma > 1 \leftrightarrow -1 < \rho < 0$, if $\sigma = 1$, then $\alpha > \beta$ such that R_{NN} is non-essential	Production input	Production inputs without which production of consumer goods is not possible (a portion of natural capital)
2) Daly	$dB_{K_M}/dt > 0$ $and\ dT/dt = 0$	$K_N \geq K_N^*\ and\ F_C \geq F_C^*$ $dK_{NR}/dt \geq 0\ and\ dF_C/dt \geq 0$ $-dK_{NN}/dt + dK_{NR}/dt \geq 0$	Stocks of low-entropy resources	Production inputs without which production of consumer goods is not possible (all natural capital)
3) Ekins	$dW^{Env}/dt \geq 0$ $dW^{Econ}/dt \geq 0$ $dW^{Soc}/dt \geq 0$ $dW^{Eth}/dt \geq 0$	$EF \geq EF^*$	Stocks providing environmental functions: Source, Sink, Life-support, and Amenity	Stocks performing environmental functions with characteristics of non-substitutable and irreversible/immoderate loss
4) Pearce–Turner	$dW_t/dt \geq 0$	$d\boldsymbol{K}/dt \geq 0$ or, $d\boldsymbol{K}/dt \geq 0\ and\ dK_N/dt \geq 0$	Stocks providing Resource flow, Waste sink, Amenity, Life-support function	Stocks providing life-support function

where C_t is consumption, W_t is welfare, σ is elasticity of substitution defined per equation (5), ρ is discount rate, α, β are elasticity of output with respect to manufactured capital and natural capital respectively, K_{NN} is non-renewable resource stock, K_{NR} is renewable resources stock, $\boldsymbol{K}$ is total capital stock, B_{K_M} is benefit from manufactured capital, T is throughput, K_N is natural capital stock, EF is critical environmental function (service flow), EF^* is critical level (threshold) of environmental function, and W^{Env}, W^{Econ}, W^{Soc}, W^{Eth} are each dimension of welfare in Ekins' sustainability which cannot be added up.

Table 1 displays how natural capital is positioned within the theory of SD in each approach to sustainability, and also summarizes how, as a response to the essential question of SD ('What is to be sustained?'), the concept of CNC is derived.

5. Conclusion

This paper classifies the economic theories of SD into four approaches to sustainability, namely, (1) Solow–Hartwick's sustainability, (2) Daly's sustainability, (3) Ekins' sustainability, and (4) Pearce–Turner's sustainability, and clarifies the theoretical basis of the concept of CNC, which has been interpreted and used in various ways, by examining how each approach recognizes SD and captures natural capital in its theoretical framework.

The results imply, first, theoretical differences among the four approaches to sustainability come from differences in not only the concept and interpretation of both natural capital and CNC, but also the answer to the fundamental question of what is to be sustained in SD. When we use the term "natural capital" we must be certain which approach to sustainability we have in mind. Although there is an opinion that the term is an interface between economics and ecology (see Fenech et al. 2003), we cannot discuss anything in a constructive manner by merely using the term "natural capital" or "CNC" unless we clarify the theoretical basis on which we depend.

Second, every approach has a common feature of *not denying* the constant capital rule (expressions 23 and 24) as long as it is regarded as a minimum necessary condition for the achievement of SD. In discussions on how SD is achieved, differences arise among the four approaches to sustainability as they depend on different economic theories of SD. It is inevitable that the concept of CNC, which represents what must be maintained to achieve SD, should be discussed along with the economic theories of SD. CNC should not be discussed solely within the realm of physical non-substitutability, but should be discussed as a vital part of the economic theories of SD.

Third, what is important is the determination of the critical level (threshold) of natural capital under uncertainty such that CNC contributes to policy making towards SD, and we ought to examine particularly how to take into account the social aspects of CNC. We cannot determine *a priori* which forms of natural capital are truly needed by people, and the level of natural capital to be maintained will depend on how much welfare loss people can endure. Eventually, the issue of operationalizing the concept CNC comes to the determination of its critical level (threshold). However, the critical level (threshold) of each type of natural capital and the extent of negative effects of not meeting that level are intrinsically uncertain. These kinds of existing uncertainty make it difficult to determine the critical level (threshold) of natural capital from a purely scientific point of view.

Determining the critical level (threshold) of natural capital under uncertainty is not at all an easy task, for it is related not only to its physical aspects, but also to its economic, political, and ethical aspects. However, there is no excuse for not tackling the decision problem simply because it is not an easy task. As is clear from the analysis, we must have deeper discussions on the determination of the critical level (threshold) under uncertainty from a multidimensional point of view. This moves us towards the operationalization of the concept of CNC which is an important issue in achieving SD and contributes to the determination regarding which forms of and how much natural capital should be passed on to future generations.

References

Beckerman, W. (1995), "How would you like your 'sustainability', sir? Weak or Strong? A reply to my critics", *Environmental Values* **4**, pp.169-179.

Boulding, K. (1966), "The economics of the coming spaceship Earth", in Jarrett, H. (ed), *Environmental Quality in a Growing Economy*, Baltimore: Johns Hopkins University Press.

Boulding, K. (1968), *Beyond Economics: Essays on Society, Religion, and Ethics*. The University of Michigan Press: Michigan.

Brown, G.M. and Field, B. (1979), "The adequacy of measures for signaling the scarcity of natural resources". In: Smith, U.K. (Ed.), *Scarcity and Growth Reconsidered*. John Hopkins Press, Baltimore, pp.218-248.

Chiang, A.C. and Wainwright, K. (2005), *Fundamental Methods of Mathematical Economics*, Fourth edition, McGraw Hill: New York.

Chiesura, A. and de Groot, R. (2003), "Critical natural capital: a socio-cultural perspective", *Ecological Economics* **44**, pp.219-231.

Ciriacy-Wantrup, S.V. (1952), Resource Conservation: Economics and Policies, Berkeley: University of California Press.

Costanza, R. and Daly, H. (1992), "Natural capital and sustainable development", *Conservation Biology* **6**(1), pp.37-46.

Daly, H. (1974), "The economics of the steady state", *The American Economic Review* **64**(2), Papers and Proceedings of the Eighty-sixth Annual Meeting of the American Economic Association, pp.15-21.

Daly, H. (1979), "Entropy, growth, and the political economy of scarcity", in: Smith, V. K. (ed.), *Scarcity and Growth Reconsidered*, pp.67-94, Baltimore: Resource For the Future and Johns Hopkins Press.

Daly, H. (1990), "Toward some operational principles of sustainable development", *Ecological Economics* **2**, pp.1-6.

Daly, H. (1991), "Elements of environmental macroeconomics", in: Costanza, R. (ed), *Ecological Economics: the Science and Management of Sustainability*, New York: Columbia University Press.

Daly, H. (1994), "Operationalizing sustainable development by investing in natural capital", in: Jansson, A., Hammer, M., Folke, C. and Costanza, R. (eds), *Investing in Natural Capital: The Ecological Economics Approach to Sustainability*, Washington: Island Press.

Daly, H. (1995), "On Wilfred Beckerman's critique of Sustainable Development", *Environmental Values* **4**, pp.49-55.

Daly, H. (1996), *Beyond Growth: The Economics of Sustainable Development*, Boston: Beacon Press.

Daly, H. and Farley, J. (2004), Ecological Economics: Principles and Applications, Washington D.C.: Island Press.

Dasgupta, P. and Heal, G. (1979), *Economic Theory and Exhaustible Resources*, Cambridge University Press: Cambridge.

Deadman, D. and Turner, R.K. (1988), "Resource conservation, sustainability and technical change". In: Turner, R.K. (Ed.), *Sustainable Environmental Management Principles and Practice*,

Belhaven Press, London, pp.67-101.
De Groot, R. (1992), *Functions of nature: evaluation of nature in environmental planning, management and decision making*, Wageningen: Wolters-Noordhoff BV.
De Groot, R., Van der Perk, J. and Chiesura, A. and Van Vliet, A. (2003), "Importance and threat as determining factors for criticality of natural capital", *Ecological Economics* **44**, pp.187-204.
De Groot, R., Hein, L., Kroeze, C. Leemans, R. and Niemeijer, D. (2006), "Indicators and measures of critical natural capital", in: Lawn, P. (ed), *Sustainable Development Indicators in Ecological Economics*, Cheltenham: Edward Elgar.
Deustch L., Folke C. and Ska°nberg, K. (2003), "The critical natural capital of ecosystem performance as insurance for human well-being", *Ecological Economics* **44**, pp.205-217.
Douguet, J-M. and O'Connor, M. (2003), "Maintaining the integrity of the French terroir: a study of critical natural capital in its cultural context", *Ecological Economics* **44**, pp.233-254.
Dubourg, W.R. (1992), "The sustainable management of the water cycle: a framework for analysis", *CSERGE Working Paper* WM-07.
Dubourg, W.R. (1993), "Sustainable management of the water cycle in the UK", *CSERGE Working Paper* WM-02.
Ekins, P. (2000), *Economic Growth and Environmental Sustainability: The Prospects for Green Growth*, London and New York: Routledge.
Ekins, P. (2003a), "Identifying critical natural capital", *Ecological Economics* **44**, pp.159-163.
Ekins, P. (2003b), "Identifying critical natural capital: Conclusions about critical natural capital", *Ecological Economics* **44**, pp.277-292.MacDonald, D.V., Hanley, N. and Moffatt, I. (1999), "Applying the concept of natural capital criticality to regional resource management", *Ecological Economics* **29**, pp.73-87.
Ekins, P. and Simon, S. (2003), "An illustrative application of the CRITINC framework to the UK", *Ecological Economics* **44**, pp.255-275.
Ekins, P., Simon, S., Deutsch,L. Folke,C. and De Groot,R. (2003), "A framework for the practical application of the concepts of critical natural capital and strong sustainability", *Ecological Economics* **44**, pp.165-185.
English Nature (1994), *Sustainability in Practice, issue 1, Planning for Environmental sustainability*, English Nature, Peterborough, UK.
Farley, J. (2008), "The role of prices in conserving critical natural capital", *Conservation Biology*, **22**(6), pp.1399-1408.
Fenech, A., Foster, J., Hamilton, K., and Hansell, R. (2003), "Natural Capital in Ecology and Economics: An Overview", *Environmental Monitoring and Assessment,* **86**(1-2), pp.3-17.
Georgescu-Roegen, N. (1971), *The Entropy Law and the Economic Process*, Cambridge: Harvard University Press.
Georgescu-Roegen, N. (1975), "Energy and economic myths", *Southern Economic Journal,* **41**(3), pp.347-381.
Georgescu-Roegen, N. (1979), "Comments on the Papers by Daly and Stiglitz Nicholas Georgescu-Roegen", in: Smith, V. K. (ed.), *Scarcity and Growth Reconsidered*, pp.95-105, Resource for the Future and Johns Hopkins Press, Baltimore, MD.
Gutes, M.C. (1996), "The concept of weak sustainability", *Ecological Economics* **17**(3), pp.147-156
Hartwick, J.M. (1977), "Intergenerational equity and the investing of rents from exhaustible resources", *American Economic Review* **67**, pp.972-974.
Hartwick, J.M. (1978a), "Substitution among exhaustible resources and intergenerational equity", Review of Economic Studies 45, pp.347-354.
Hartwick, J.M. (1978b), "Investing returns from depleting renewable resource stocks and intergenerational equity", *Economic Letters* **1**, pp.85-88.
Hartwick, J.M. (1994), "National Wealth and Net National Product", *The Scandinavian Journal of Economics* **96**(2), pp.253-256.
Hicks, J.R. (1946), *Value and Capital*, Oxford University Press: Oxford.
Hueting, R., (1974), *New Scarcity and Economic Growth*, North-Holland: Elsevier.
Maler, K-G. (1986), "Comment on R. M. Solow, "On the Intergenerational Allocation of Natural Resources"", *Scandinavian Journal of Economics* **88**(1), pp.151-152.
Maler, K-G. (1991), "National accounts and environmental resources", *Environmental and Resource Economics* **1**, pp.1-15.
Meadows, D.H. (1972), *The Limits to growth: a report for the Club of Rome's project on the predicament of mankind*, New York: Universe Books.
Neumayer, E. (2003), *Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*, Second Edition, Edward Elgar, Cheltenham/Northampton.

Nishimura, K. (1990), *Microeconomics*, ToyokeizaiShinposha (written in Japanese).

Noel, J-F. and O'Connor, M. (1998), "Strong sustainability and critical natural capital", in J-F. Noel and M. O'Connor (eds.), *Valuation for Sustainable Development: Methods and Policy Indicators*, Chapter 4., pp.75-97, Edward Elgar, Cheltenham, UK/ Northampton, MA, USA.

Ozkaynak, B., Devine, P. and Rigby, D. (2004), "Operationalising strong sustainability: Definitions, methodologies and outcomes", *Environmental Values* 13, pp.279-303.

Pearce, D. (1997), "Substitution and sustainability: some reflections on Georgescu-Roegen", *Ecological Economics* 22, pp.295-297.

Pearce, D.W. (1998), *Economics and Environment: Essays on Ecological Economics and Sustainable Development*, Cheltenham: Edward Elgar.

Pearce, D., and Turner, R.K. (1990), *Economics of Natural Resources and the Environment*, Baltimore: The John Hopkins University Press.

Pearce, D.W., Atkinson, G.D. (1993), "Capital theory and the measurement of sustainable development: an indicator of "weak" sustainability", E*cological Economics* 8(2), pp.103-108.

Pearce, D.W., Warford, J.J. (1993), *World without End: Economics, Environment, and Sustainable Development*, Oxford University Press.

Pearce, D.W., Markandya, A. and Barbier, E. (1989), Blueprint for a Green Economy, London: Earthscan Publications.

Pearce, D.W., Barbier, E., and Markandya, A. (1990), *Sustainable Development: Economics and Environment in the Third World*, Edward Elgar: London.

Pearce, D., Turner, R.K., Dubourg, R., and Atkinson, G. (1993), "The conditions for sustainable development", in D. Pearce (ed.), *Blueprint 3: Measuring Sustainable Development*, pp. 15-27, CSERGE, London: Earthscan Publications.

Pearce, D.W., Atkinson, G.D., and Dubourg, W.R. (1994), "The economics of sustainable development", *Annual Review of Energy and the Environment* 19, pp.457-474.

Perman, R., Ma, Y., McGilvray, J. and Common, M. (1999), *Natural Resource and Environmental Economics*, Second edition, Pearson Education Limited: Harlow.

Sagoff, M. (1995), "Carrying capacity and ecological economics: Comment", Bioscience, 45(9), pp.610-620.

Solow, R.M. (1974), "The economics of resources or the resources of economics", *American Economic Review* 64(2), pp.1-14.

Solow, R.M. (1986), "On the Intergenerational Allocation of Natural Resources", *Scandinavian Journal of Economics* 88(1), pp.141-149.

Stiglitz, J.E. (1979), "A neoclassical analysis of the economics of natural resources", in: Smith, V. K. (ed.), *Scarcity and Growth Reconsidered*, pp.36-66, Baltimore: Resource For the Future.

Townsend, K.N. (1992), "Is entropy law relevant to the economics of natural resource scarcity? Comment", *Journal of Environmental Economics and Management* 23, pp.96-100.

Turner, R.K. (1993), "Sustainability: Principles and Practice", in R.K. Turner (ed.), *Sustainable Environmental Economics and Management: Principles and Practice*, pp.3-36, London/New York: Belhaven Press.

Turner, R.K. (1997), "Georgescu-Roegen versus Solow/Stiglitz: a pluralistic and interdisciplinary perspective", *Ecological Economics* 22, pp.299-302.

Turner R.K., Pearce, D. and Bateman, I. (1994), *Environmental Economics: An Elementary Introduction*, Harvester Wheatsheaf.

Appendix: Definitions of Critical Natural Capital

	Definition	Examples of CNC	Characteristics
Pearce et al. 1993	Ecological assets which are essential for human well-being and survival	Experience of space and amenity; Basic biogeochemical cycles; Ozone layer; Carbon cycles	Essentiality for humans
Pearce and Warford 1993	Loss of it will inevitably worse off future generation's welfare and cannot be compensated	Ozone layer; Tropical forests; Carbon cycles	Intergenerational equity
Turner 1993	Certain types of natural capital which is non-substitutable by man-made capital and its stocks need to be consistent with ecosystem stability and resilience	Keystone species/processes; Environmental support services	Functional substitutability
Turner et al. 1994	Ecological elements, functions and services which are essential for human well-being and survival	Biogeochemical cycling; Landscape, space, relative peace, quiet	Essentiality for humans
English Nature 1994	Ecological assets, stock levels or quality levels which are highly valued, irreplaceable/ non-substitutable, and essential either to human health or efficient functioning of life support systems	- (*1)	Essentiality for humans; Functional substitutability
Noel and O'Connor 1998; Faucheux and O'Connor 1999	Set of environmental resources which performs important environmental functions and non-substitutable by man-made, human or natural capital itself	Primary energy source; Atmosphere; Forest ecosystems; Freshwater resources; Genetic diversity; Arable land; Ocean fisheries	Functional substitutability
Dobson 1998	Natural capital which is critical to the production and reproduction of human life and pre-conditional for survival	Primary goods; Large scale 'ecological processes'; 'biogeochemical cycles; 'global life support systems'; Ecological 'glue'	Distributive justice
MacDonald et al. 1999	imperfect substitutability of natural and manmade capital	Air; Soil; Water; Flora and fauna (terrestrial and aquatic)	Functional substitutability
Ekins 2000	'natural capital which is responsible for important environmental functions and which cannot be substituted in the provision of these functions by manufactured capital."	Water; Air; Minerals; Energy; Space; Genetic Materials; Stratospheric ozone layer	Functional substitutability
Ekins 2003a,b; Ekins et al. 2003	Natural capital which performs important environmental functions and non-substitutable by man-made, human or natural capital itself	Global climate; Ozone layer; Biodiversity; Landscape; Air; Water; Forest; Land; Coastal wetlands;	Functional substitutability; Essentiality for humans and ecosystems
Farley 2008	'…consists of those resources of nature essential for sustaining human welfare and for which substitution is difficult or impossible.'	Biodiversity loss; Climate change	Essentiality; Substitutability

(*1) English Nature (1994) is quoted in MacDonald et al. (1999), but I could not access to the original document because it is a kind of government document which eliminates an access other than British people. Under this circumstances, the examples of CNC in English Nature (1994) cannot be specified.

Revisit the Consequences of Consequentiality

Chih-Chen Liu

Chih-Chen Liu is assistant professor of Applied Economics at National University of Kaohsiung. Permission to use the data from Iowa Lakes Project developed by Catherine L. Kling and Joseph A. Herriges is greatly appreciated.

Correspondence: Chih-Chen Liu, Department of Applied Economics, National University of Kaohsiung, 700, Kaohsiung University Rd., Nanzih District, 81148. Kaohsiung, Taiwan, R.O.C. E-mail: ccliu@nuk.edu.tw. Tel: 886-7-591-9768. Fax: 886-7-591-9321.

Revisit the Consequences of Consequentiality

Abstract: Carson and Groves (2007) suggest that individuals can be expected to answer a dichotomous choice referendum question in a stated preference survey truthfully if they perceive the results of the survey will influence a policy outcome they care about, i.e. *policy consequentiality*, and if they must pay for it, i.e. *payment consequentiality*. This argument, thus, indicates that data arising from individuals who perceive the results of the survey both policy consequential and payment consequential can be expected to provide truthful answers to survey questions. However, the direction of bias could not be predicted if individuals perceive the results of the survey either not policy consequential or not payment consequential. Using survey data from the Iowa Lakes Project, we examine how policy consequentiality and payment consequentiality would influence their votes on a dichotomous choice referendum in the survey. We find that policy consequentiality and payment consequentiality seem to have different effects on individuals' votes on a referendum: (1) policy consequentiality relates to whether or not individuals will vote on the referendum economically, and (2) payment consequentiality relates to whether or not individuals will vote on the referendum strategically.

Keywords: non-market valuation, consequentiality, contingent valuation

1. Introduction

Stated preference method is widely employed by economists in surveys to determine the relevant public's preferences for non-market goods or services. Based on the neoclassical economic framework, Carson and Groves [5] suggest that individuals can be expected to vote on a standard dichotomous choice referendum truthfully if they perceive the results of the survey will influence a policy outcome they care about, i.e. *policy consequentiality*, and if they must pay for it, i.e. *payment consequentiality*.[1] That is, if individuals perceive the results of the survey both policy consequential and payment consequential with any positive probability, then their preferences would be ultimately influenced by the results of the survey. As a result, their dominant strategy would be truthfully and fully revealing their preferences. On the contrast, if the results of the survey are perceived either not policy consequential or not payment consequential, then the results of the survey would have no influences on individuals' preferences. Consequently, individuals would provide any answers, either truthful or not.

If the proposition suggested by Carson and Groves were correct, it would not only provide researchers important insights in assessing the reliability of empirical results of

[1] The notions of policy consequentiality and payment consequentiality refer to Herriges et al. [12]

studies using stated preference method, but also a basis for handling survey responses: making use of the information elicited from individuals who perceive the results of the survey both policy consequential and payment consequential only to make inferences of the welfare measure of interests. However, Carson and Groves do not make predictions about the direction of bias when a survey is viewed either not policy consequential or not payment consequential.

In this paper, we examine the effects of policy consequentiality and payment consequentiality on individuals' votes on a standard dichotomous choice referendum. The next section presents a brief overview of related studies. Section 3 describes the data required to test the effects of consequentialities, which are obtained from the 2003 Iowa Lakes Survey. The empirical results are reported in Section 4. Concluding remarks are offered in Section 5.

2. Related Literature

Whether or not a dichotomous choice referendum employed in a stated preference survey is incentive compatible is critical for assessing the validity of the welfare measure of interests. Most tests concerned with the impacts of consequentialities on individuals' preference revelation have been conducted through laboratory or field experiments. In these experiments, payment consequentiality is typically bound to policy consequentiality and both conditions are characterized by the researchers. For example, Cummings et al. [9] conduct a laboratory experiment to test whether or not a hypothetical referendum is incentive compatible. Comparing individuals' voting behaviors either in a real or a purely hypothetical referendum, they find that individuals are more likely to vote "yes" on a purely hypothetical referendum than on a real one. They conclude that a purely hypothetical referendum would yield biased willingness to pay (WTP) estimates.

Cummings and Taylor [10] further investigate the issue by altering the probability of a referendum being binding. They find that individuals' voting behaviors are correlated with the degree of consequentiality. In particular, the percentage of "yes" responses falls when the probability of a referendum being binding rises. They also find that only if the probability of the referendum being binding is greater than 50%, an individual would vote as a real referendum.

Carson et al. [6] examine the impacts of consequentiality in a field experiment where the probability of a referendum being binding is controlled. Contrary to Cummings and Taylor [10], they find that, with any positive probability of a referendum being binding, individuals would vote as a real referendum. That is, individuals' voting behaviors are independent of the degree of consequentiality.

In these studies, researchers characterized the joint effects of policy and payment consequentialities and test how the degree of consequentiality in associated experiments influences individuals' voting behaviors in a referendum. However, individuals' perceiving policy and payment consequentialities are normally not controlled in surveys. To test the effects of policy consequentiality on individuals' votes, within a survey context, Bulte et al. [4] provided individuals different information treatments, such as a policy consequentiality treatment or a cheap talk, in split samples to investigated the impacts of these information treatments on individuals' voting behaviors. Particularly, individuals who received the policy consequentiality treatment were informed that the results of the survey will be available to policy makers. Their results suggest that the estimated willingness to pays elicited from individuals who obtained the policy consequentiality or the cheap talk treatment are significantly lower than that from a purely hypothetical referendum.

Instead of describing the degree of policy consequentiality in the questionnaire, Herriges et al. [12] ask individuals' to report their perceiving policy consequentiality on a 5-point scale. In order to control the potential endogeniety in individuals' reported policy consequentiality, an information treatment that provides compelling evidence of policy consequentiality of the survey is randomly offered to a subsample. They find similar willingness to pay distributions among individuals who reported positive degree of policy consequentiality, but a statistically different WTP distribution for those who perceive the survey not consequential at all.

Regarding the effects of payment consequentiality, Champ et al. [7] employ an actual donation and a contingent donation survey to investigate the effectiveness of a contingent donation survey in estimating the value of an unfamiliar environmental good. In the contingent donation survey, a follow-up certainty question, on a 10-point scale with a “10” denotes “very certain”, is used to measure individuals’ certainty with respect to their vote on the referendum. Comparing to the actual donation data, they find that hypothetical donation yields biased estimated willingness to donate. Additionally, recoding all uncertain “yes” responses as “no”, the magnitudes of estimated willingness to donate are similar in both samples. Their results suggest the effectiveness of the follow-up certainty question in differentiating individuals who would actually pay from those who would not in surveys. Similar results are provided by Blumenschein et al [3], Vossler et al. [13], and Blomquist et al. [2].

3. The Data

This study employs data from the 2003 survey of the “Iowa Lakes Project”. The Iowa Lakes Project is a four-year study aimed at understanding recreational use and the economic value of water quality in the primary recreational lakes in Iowa. The project began in 2002 with mail surveys sent out to a random sample of 8,000 Iowa residents, obtaining detailed information regarding their visitation patterns to 132 lakes, as well as standard socioeconomic data such as age, income, gender, and education. In subsequent years, surveys were sent to those individuals who completed a survey in the previous years.[2] Standard follow-up procedures were employed, including a postcard reminder mailed two weeks after the initial mailing and a second copy of the survey mailed one month later. Individuals were provided a $10 incentive for completing the survey.

Essential elements of this study involve the proposition of a standard dichotomous choice referendum for water quality improvement at eight focus lakes, and the elicitation of individuals' perceptions of payment consequentiality and policy consequentiality. Each of the elements is discussed in turn.[3]

3.1. *The Proposition of the Referendum*

A dichotomous choice referendum aimed at estimating individuals' willingness to pay (WTP) for a water quality improvement project at one of eight focus lakes targeted

---

[2] A second random sample was added into the panel in 2003 to fill in for the non-deliverable surveys in 2002 and returned the sample to a total of 8000 individuals. No additional individuals were added after 2003.

[3] A version of the dichotomous choice referendum associated with one of the focus lakes is provided in Appendix.

in the study was included in the 2003 and the 2005 versions of the questionnaire. These lakes were selected in consultation with the Iowa Department of Natural Resources. In addition to being geographically dispersed, they were each of policy interests as various restoration projects were being considered at the lakes.

The survey first described the current water quality of the lake targeted, including water clarity, water color, water odor, health concerns from algae blooms and bacteria levels, and the variety and quantity of fish. A photograph depicting the water clarity and water color was provided to the respondents to help them visualize the water quality of the lake. In a further attempt to encourage the respondents truthfully revealing their preferences, a cheap talk about the incentive and information properties of the referendum was also provided.

A water quality improvement project regarding the focus lake was then proposed. After outlining the targets and methods to achieve the water quality level at the focus lake, individuals were asked whether they would vote in favor of a referendum to improve the water quality in a specific lake where the cost (ranging from \$100 to \$600 payable over a five-year period) were randomly assigned.

3.2. ***The Payment Consequentiality***

Based on the consistent results supporting the effectiveness of the follow-up certainty question in assessing individuals' payment consequentiality, we use a follow-up certainty question similar to Champ et al. [7] to measure individuals' certainty of payment with respect to their responses to the referendum and consider their answers as a proxy of payment consequentiality. Specifically, individuals were asked the following question: "How sure are you of this answer?" Possible answer to this question ranged from 1 to 5 where a "1" denotes "not sure at all' and a "5" denotes "certain".

Table 1 provides a summary of the 2003 data categorized by the level of payment consequentiality. The data first indicates that most individuals had some confidence on their responses to the referendum. Second, compared with individuals who perceived some positive certainty about their responses to the referendum, individuals who were "not sure at all" about their responses to the referendum not only had the lowest percentage of "yes" responses but also had some differences in socioeconomic characteristics: lower percentage of males, lower percentage of college graduates, lower average income, and greater average age. Third, individuals who were "definitely sure" (i.e. anyone who reported a 5 to the follow-up certainty question) about their responses to the referendum had a lower "yes" response rate than individuals who were "probably sure" (i.e. anyone who reported a 2, 3, or 4 to the follow-up certainty question).

3.3. *The Policy Consequentiality*

To elicit individuals' perceived policy consequentiality of the survey, individuals were asked the following question: "How likely do you think it is that the results of surveys such as the one will affect decisions about water quality in Iowa lakes?" Possible responses to this question ranged from 1 to 5 where a "1" denoted "no effect at all" (i.e., completely not policy consequential) and a "5" denoted "definite effect" (definitely policy consequential). We refer individuals' answer to the question as a proxy for policy consequentiality.

Table 2 reports a summary of 2003 data categorized by levels of policy consequentiality. First, most respondents perceived some degree of policy consequentiality of the survey results. Second, compared with individuals who perceived some positive degree of policy consequentiality (i.e. anyone who reported a 2, 3, 4, or 5 to the policy consequentiality question), individuals who perceived the survey as being completely not policy consequential (i.e. anyone who reported a "1" to the policy consequentiality question) had the lowest "yes" rate among the sample and a lower percentage of college graduates. Third, the percentage of "yes" responses increased with the degree of policy consequentiality individuals perceived.

4. Empirical Results

A simple story regarding how individuals' perceived policy and payment consequentialities influence their voting behaviors on a dichotomous choice referendum is illustrated in Figure 1 and Figure 2. In particular, Figure 1 represents the voting patterns of individuals who perceived positive degree of policy consequentiality of the survey. These individuals are divided into five subgroups by their reported certainty about their votes on the referendum. It is shown that the percentage of "yes" responses falls as the cost of provision rises for those individuals who had some confidence on their votes. However, the cost of provision does not have influence on the percentage of "yes" responses for those individuals who were "not sure at all" about their votes on the referendum. Furthermore, individuals who were "definitely sure" about their votes on the referendum appears to have lower rates of "yes" responses than other subgroups at each cost value.

Figure 2 represented the voting patterns of individuals who perceived the survey completely not policy consequential. Apparently, whether or not individuals were certain about their responses to the referendum, the "yes" rates seemed not to be influenced by the personal cost of provision. Similar to what we observe in Figure 1, individuals who were "definitely sure" about their votes on the referendum have lower rates of "yes" responses among the subgroups.

The voting patterns illustrated in the above figures might suggest that policy and payment consequentialities of a survey could have different effects on individuals' votes on a dichotomous choice referendum. The hypotheses associated policy and payment consequentialities with individuals' votes are summarized as follows:

Hypothesis 1: Policy consequentiality relates to whether or not individuals will vote on a referendum economically.

That is, if individuals perceive positive degree of policy consequentiality of the survey, i.e. the results of the survey will influence relevant policy outcomes they care about, and then they would be less likely to vote in favor of a referendum as the cost of provision for the amenity increases. However, if individuals perceive the survey results would definitely not influence relevant policy outcomes, and therefore their preferences, then they might answer the referendum with any decision rule. Consequently, we could find that the cost of providing the amenity does not influence individuals' votes as the economic theory would predict.

Hypothesis 2: Payment consequentiality relates to whether or not individuals will vote on a referendum strategically.

Specifically, individuals who were not definitely sure about their votes on the referendum may perceive that there is some probability they do not have to actually pay for the provision of the amenity if the referendum passed. On the contrary, individuals who were “definitely sure” about their votes on the referendum may perceive that they will have to actually pay for the amenity if the referendum passed. Therefore, a lower probability of voting “yes” for those individuals who were “definitely sure” about their votes on the referendum is expected.

We use the random utility maximization model developed by Hanemann [11] to formally examine the validity of the hypotheses. In particular, individuals are first divided into five subsamples by the degree of policy consequentiality they perceived. In each subsample, individuals are further categorized into five groups by the degree of payment consequentiality they perceived. By including an intercept and omitting the group of individuals who perceived definite payment consequentiality so that the coefficients associated with all other groups are interpreted relative to the excluded group.

Table 3 summarized the empirical results of our hypotheses testing. In particular, regarding the effect of policy consequentiality on individuals’ votes, hypothesis 1 suggests that the cost of provision would negatively influence individuals’ likelihood of supporting the referendum if they perceive positive degree of policy consequentiality. However, the cost of provision could influence individuals’ votes in any direction if they perceive the survey completely not policy consequential. Focusing on the estimated coefficients associated with the cost of provision in each subsample, our results support the prediction of hypothesis 1. On the one hand, the negative coefficients associated with the cost of provision for subsamples with positive degree of policy consequentiality suggest that the cost of provision would definitely influences their likelihood of voting “yes” on the referendum in the negative direction. On the other hand, the negative coefficient with a low probability for the subsample perceiving completely not policy consequential suggests that the cost of provision could influence their likelihood of voting “yes” on the referendum either in the positive or in the negative direction.

Furthermore, hypothesis 2 suggests that the group perceiving definite payment consequentiality would be less likely to vote “yes” on the referendum than other groups. Consistent with the prediction of hypothesis 2, our result suggest that, in each subsample, relative to the baseline group, individuals not perceiving definite payment consequentiality were apparently more likely to vote “yes” on the referendum in most cases.

5. Concluding Remarks

Carson and Groves [5] suggest that individuals can be expected to vote on a dichotomous choice referendum economically if they perceive the survey as being both policy consequential and payment consequential. However, their proposition does not point out the direction of bias when the survey is either not policy consequential or payment consequential. This paper is a complementary study of Carson and Groves [5]. Specifically, we use information elicit from individuals to examine the role of policy consequentiality and payment consequentiality on individuals' votes on a dichotomous choice referendum. We find that individuals who perceive the survey not definitely payment consequential might vote on a referendum strategically. We also find that only individuals who perceive positive degree of policy consequentiality of the survey can be viewed to vote on a referendum economically.

References

[1] Albert, J. H., and S. Chib, 1993. "Bayesian Analysis of Binary and Polychotomous Response Data." *Journal of American Statistical Association* 88: 669-679.

[2] Blomquist, G. C., K. Blumenschein, M. Johannesson, 2008. "Eliciting Willingness to Pay without Bias using Follow-up Certainty Statements: Comparisons between Probably/Definitely and a 10-point Certainty Scale" *Environmental and Resource Economics* 43:473-502.

[3] Blumenschein, K., M. Johannesson, G. C. Blomquist, B. Liljas, and R. M. O'Conor, 1998. "Experimental Results on Expressed Certainty and Hypothetical Bias in Contingent Valuation." *Southern Economic Journal* 65: 169-177.

[4] Bulte, E., S. Gerking, J. A. List, and A. Zeeuw. 2005. "The Effect of Varying the Causes of Environmental Problems on Stated WTP Values: Evidence from a Field Study." *Journal of Environmental Economics and Management* 49: 330-342.

[5] Carson, R.T. and Groves, T., 2007. "Incentive and Informational Properties of Preference Questions." *Environmental and Resource Economics* 37: 181-210.

[6] Carson, R. T., T. Groves, J. A. List, and M. J. Machina. "Probability Influence and Supplemental Benefits: a Field Test of the Two Key Assumption

underlying Stated Preferences. Working Paper, University of California, San Diego, 2004.

[7] Champ, P. A., R. C. Bishop, and T.C. Brown, 1997. "Using Donation Mechanisms to Value Nonuse Benefits from Public Goods." *Journal of Environmental Economics and Management* 33: 151-162.

[8] Cummings, R. G., G. W. Harrison, and E. E. Rugstrom, 1995. "Homegrown Values and Hypothetical Surveys: Is the Dichotomous Choice Approach Incentive Compatible?" *American Economic Review* 85:260-266.

[9] Cummings, R.G., S. Elliott, G. W. Harrison, and J. Murphy, 1997. "Are Hypothetical Referenda Incentive Compatible?" *Journal of Political Economy* 105: 609-621.

[10] Cummings, R. G., and L. O. Taylor, 1998. "Does Realism Matter in Contingent Valuation Surveys?" *Land Economics* 74: 203-215.

[11] Hanemann, W. M. 1984. "Welfare Evaluation in Contingent Valuation Experiments with Discrete Responses" *American Journal of Agricultural Economics*, 66: 332-341.

[12] Herriges, J. A., L. C. Kling, C. Liu, and J. Tobias, 2010. "What are the Consequences of Consequentiality?" *Journal of Environmental Economics and Management* 59: 67-81.

[13] Vossler, C. A., R. G. Ethier, G. L. Poe, and M. G. Welsh, 2003. “Payment Certainty in Discrete Choice Contingent Valuation Responses: Results from a Field Validity Test” *Southern Economic Journal* 69: 886-902.

Appendix

In the following sections we will ask you some questions about potential changes to the water quality of Rathbun Lake located in Appanoose County. First, however, we will give you some information on the current condition of the lake. Please read this information carefully before answering the questions that follow.

Rathbun Lake's Current Condition

The quality of a lake can be described in many ways. One measure of water quality is the clarity of the lake water. Water clarity is usually described in terms of how far down into the water an object remains visible. The clarity of Rathbun Lake is currently between 2 to 4 feet. This means that objects are visible down to about 2 to 4 feet under the surface of the water.

Current conditions of Rathbun Lake can be summarized as:

Water Clarity:	Objects distinghishable 2 to 4 feet under water
Algae blooms:	1 to 3 per year
Water color:	blue to greenish brown
Water odor:	mild to occasionally strong
Bacteria:	occasional short-term swim advisories possible
Fish:	good crappie and walleye

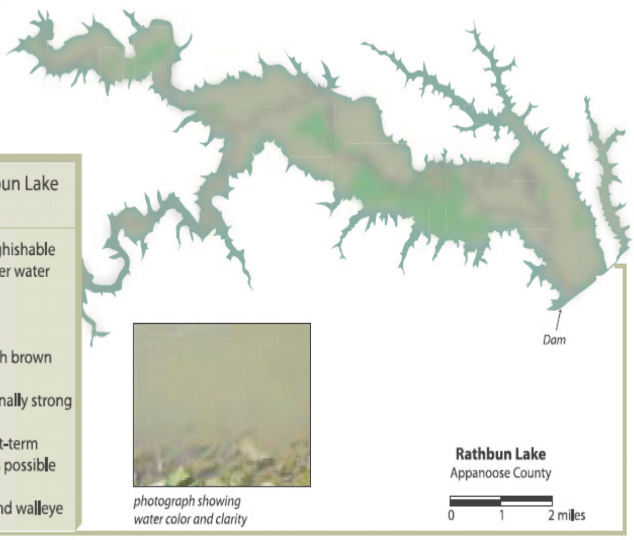


Figure 1. Current conditions of Rathbun Lake

Another measure of water quality is the amount of nutrients and other contaminants contained in the water. Water degradation can result from a number of sources, including urban runoff, fertilizers used in agriculture, motor vehicles, and others. Currently nutrients contribute to the occurrence of algae blooms in the lake, usually 1 to 3 times per year. Under some circumstances these blooms can be a health concern, causing skin rashes and allergic reactions. While Rathbun Lake is currently not regularly monitored, lakes with water quality measurements similar to those of Rathbun Lake had "Swimming is Not Recommended" signs posted by the Iowa Department of Natural Resources for anywhere from 6 to 8 weeks during a typical summer.

The overall quality of the water can affect other conditions of the lake. Poor water quality can result in an undesirable color and odor to the lake water. Currently, the color of Rathbun Lake varies between blue and greenish brown. The water usually has a mild to occasionally strong odor that many describe as "fishy."

Finally, the quality of the water affects the variety and quantity of fish in the lake. Rathbun Lake is a popular fishing lake for crappie and walleye. Catch rates for crappies are typically very good (about 120,000 annually) while walleye catches are more variable, but Rathbun Lake is the best walleye fishery in southern Iowa (about 2,000 annually). Large mouth bass and bluegill are not important sportfish species at Rathbun Lake.

4. During the course of the next year (2004), how many trips do you expect to take to Rathbun Lake?
   _____trips in 2004.

In the next question, we will be asking you how you would vote on a special ballot regarding the water quality of Rathbun Lake. While there is currently no such ballot initiative, we would like you to respond as if you were actually voting on the initiative and as if this were the only alternative available for improving water quality in the lake. (In particular, assume that no state action will be undertaken unless the referendum passes.)

When you think about your answer, it is important to keep in mind that people may indicate that they would be willing to pay more money when payment is hypothetical than when they are immediately expected to pay. It may be easy for people to say that they support a project when they are not sure they will ever have to pay any money based on their response. However, if the proposed payments are real and immediate, people may be more inclined to think about other options and what things they would have to give up to make this payment. So in answering the following questions, please keep in mind both the benefits of the water quality improvement and the impact that passage of such a referendum would have on your finances. In other words, please answer as if this were a real referendum.

Improved conditions of Rathbun Lake can be summarized as:	
Water Clarity:	objects distinguishable 6 to 8 feet under water
Algae blooms:	Rarely more than 1 per year
Water color:	green to blue
Water odor:	usually fresh
Bacteria:	rare swim advisories (most years none)
Fish:	strong walleye and high diversity

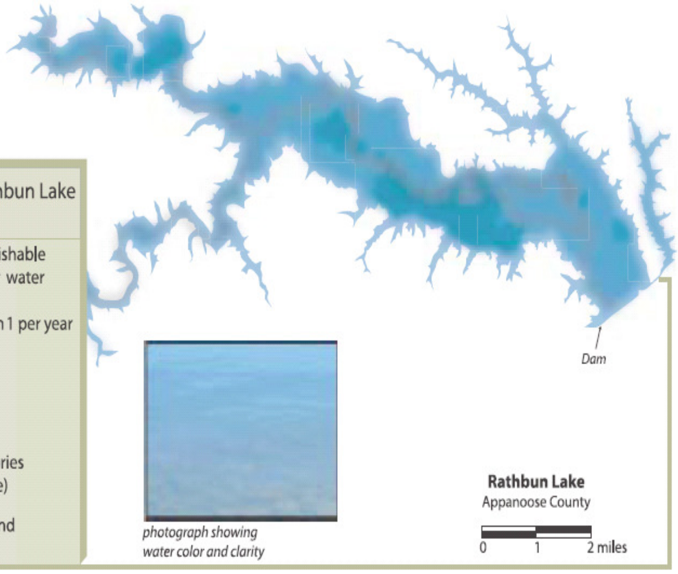


Figure 2. Conditions of Rathbun Lake following an improvement

Suppose that investments could be made to actually improve the quality of Rathbun Lake. These investments might include dredging, building protection strips along the edge of the lake to reduce runoff from the surrounding watershed or other structural changes to the lake and watershed. These changes would improve the lake over the next 5 years to the conditions described in Figure 2.

5. Would you vote "yes" on a referendum to improve the water quality in Rathbun Lake to the level described here? The proposed project would cost you $«CV BID» (payable in five $«Bid div 5» installments over a five year period.)

   ❑no ❑yes

6. How sure are you of this answer?

   1 (not sure at all) 2 3 4 5 (certain)

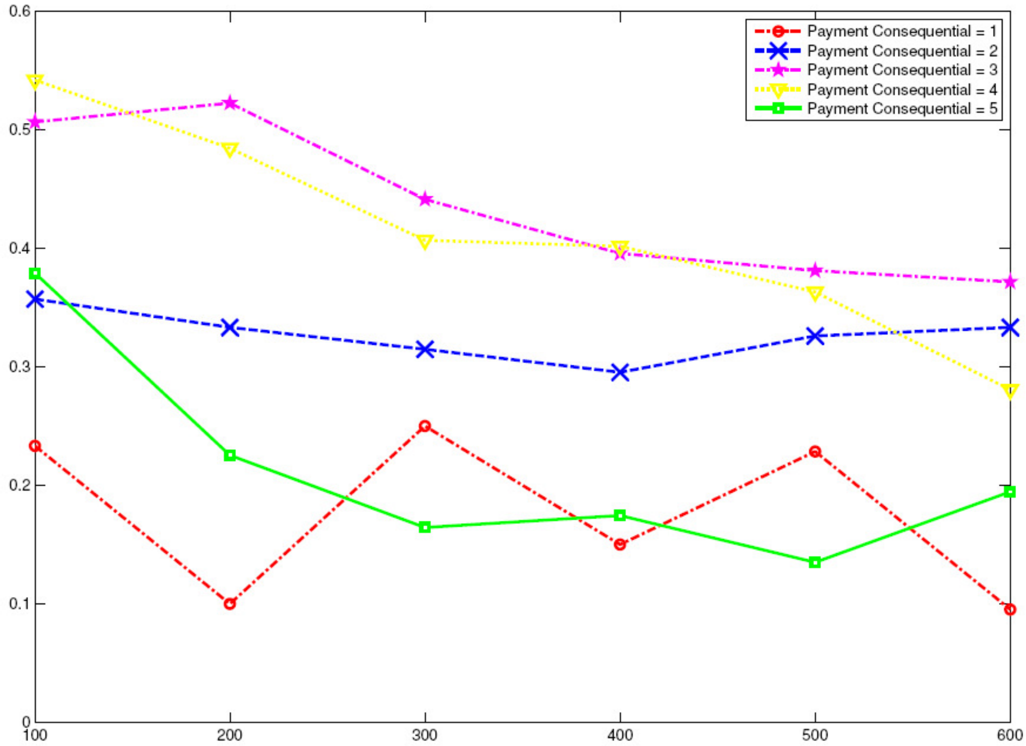


Figure 1. Individuals' Voting Patterns with Policy Consequentiality

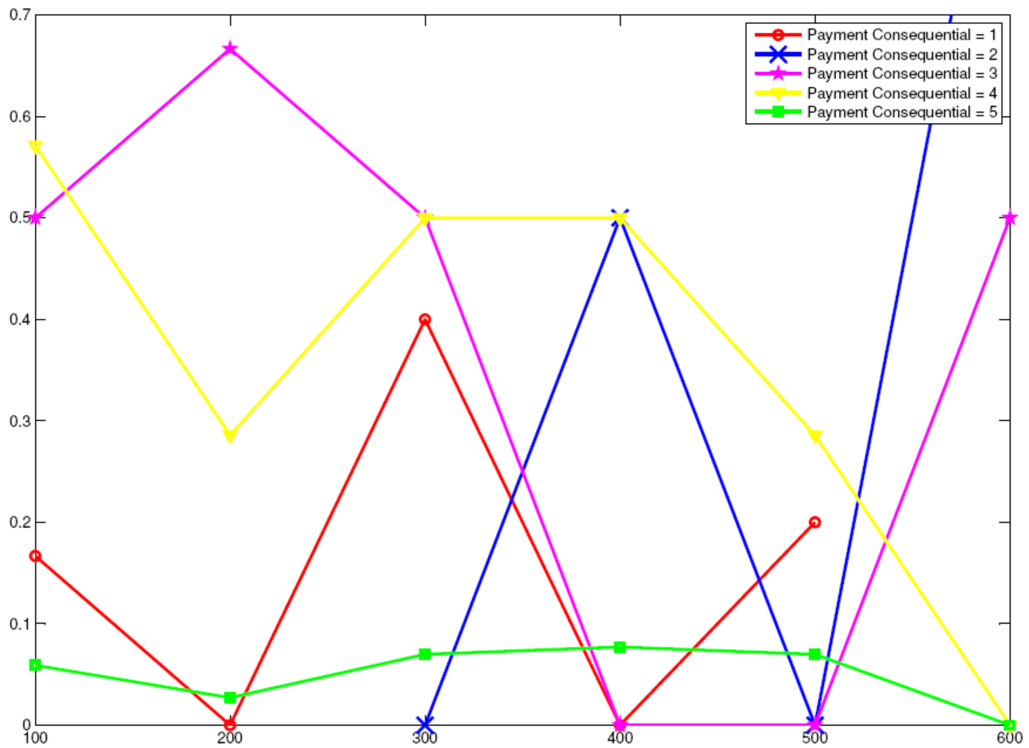


Figure 2. **Individuals' Voting Patterns without Policy Consequentiality**

Table 1. 2003 Summary Statistics by Level of Payment Consequentiality

Variable	1	2	3	4	5	Overall
Number of Observations	211	296	827	1286	2115	4735
Percentage Yes	0.18	0.33	0.44	0.42	0.20	0.31
Percentage Male	0.52	0.66	0.62	0.68	0.68	0.66
Percentage College	0.48	0.65	0.72	0.78	0.64	0.68
E(Income)	35.48	49.26	58.22	62.34	55.39	56.50
Std(Income)	24.17	33.70	36.46	36.91	37.65	36.94
E(Age)	64.50	53.17	50.98	50.13	54.60	53.10
Std(Age)	17.13	16.88	15.44	14.65	15.47	15.73

Table 2. 2003 Summary Statistics by Level of Policy Consequentiality

variable	1	2	3	4	5	Overall
Number of Observations	299	820	1979	1287	350	4735
Percentage Yes	0.13	0.27	0.30	0.35	0.38	0.31
Percentage Male	0.68	0.64	0.67	0.68	0.64	0.66
Percentage College	0.55	0.68	0.68	0.73	0.64	0.68
E(Income/1000)	55.44	59.14	55.89	58.16	49.45	56.50
Std(Income)	41.10	38.00	34.76	38.12	37.38	36.94
E(Age)	58.00	53.13	53.17	51.27	55.22	53.10
Std(Age)	16.35	15.74	15.58	15.24	16.70	15.73

Table 3. Regression Results using the Probit Model

Variable	Policy Consequentiality				
	1	2	3	4	5
Constant	-21.08	-29.21	-28.88	-37.20	2.46
	(0.04)	(0.00)	(0.00)	(0.00)	(0.56)
Not Sure at All	17.40	5.48	1.71	7.82	-45.25
	(0.98)	(0.78)	(0.58)	(0.73)	(0.00)
Moderately Sure	30.78	19.50	28.30	7.10	-3.00
	(0.99)	(1.00)	(1.00)	(0.80)	(0.42)
Probably Sure	31.52	28.94	38.51	31.76	11.41
	(1.00)	(1.00)	(1.00)	(1.00)	(0.85)
Sure	29.83	22.37	33.72	33.18	16.51
	(1.00)	(1.00)	(1.00)	(1.00)	(0.97)
Cost	-0.02	-0.04	-0.07	-0.05	-0.06
	(0.16)	(0.00)	(0.00)	(0.00)	(0.00)
Income	0.17	0.06	0.16	0.12	0.18
	(1.00)	(0.92)	(1.00)	(0.98)	(0.95)
Age	-13.54	1.01	-7.47	-7.40	-5.94
	(0.01)	(0.61)	(0.02)	(0.07)	(0.23)
Male	-2.60	0.15	-1.15	0.64	-0.86
	(0.05)	(0.56)	(0.15)	(0.69)	(0.36)
College	1.58	5.51	9.74	9.50	-3.50
	(0.60)	(0.93)	(1.00)	(0.96)	(0.33)
N	299	820	1979	1287	350

a. Numbers in the parentheses are the probabilities of the estimated coefficients being positive. Values in the parentheses near either 1 or 0 indicate a high probability of difference from zero, the former in the positive direction and the latter in the negative.

July 9, 2010
Not for circulation!

A Solution to Prisoner's Dilemma:
Full Cooperation in the Experiment with Approval Stage†

July, 2010

Tatsuyoshi Saijo*,#, Yoshitaka Okano* and Takafumi Yamakawa*
Osaka University* and UCLA#

Abstract

Players can approve or reject the other choice of the strategy after playing a Prisoner's Dilemma game. If both approve the other choice, the outcome is what they choose, and if either one rejects the other, it is the outcome when both defect. The subgame perfect equilibria of this two stage game have the outcomes where both are cooperative and both are defective. However, the all pairs of weakly evolutionarily stable strategies coincide with the subgame perfect equilibria where both are cooperative and we observed 100% cooperation in the experimental session of prisoner's dilemma game with approval stage, and 7.9% cooperation in the session of the game without the approval stage.

JEL Classification Numbers: C72, C73, C92, D74, P43

† This research was supported by "Experimental Social Sciences: Toward Experimentally-based New Social Sciences for the 21st Century" that is one of the National Projects called the Grant-in-Aid for Scientific Research on Priority Areas from the Ministry of Education, Science and Culture of Japan.

The hopelessness that one feels in such a game as this cannot be overcome by a play on the words "rational" and "irrational"; it is inherent in the situation. "There should be a law against such games!" Indeed, some hold the view that on essential role of government is to declare that the rules of certain social "games" must be changed whenever it is inherent in the game situation that the players, in pursuing their own ends, will be forced into a socially undesirable position.

Robert Duncan Luce and Howard Raiffa, *Games and Decisions: Introduction and Critical Survey*, 1957, pp.96-97.

1. Introduction

Dresher and Flood conducted the first experiment on Prisoner's Dilemma game at UCLA in January of 1950[1], and after their work, numerous papers including theory and experiment have been published in not only economics but also many fields such as mathematics, computer science, biology, psychology, sociology, political science, management science and so on[2]. There are at least three approaches in order to overcome the dilemma.

The first possible solution is to introduce repetition of the game. Kreps, Milgrom, Roberts and Wilson (1982) investigated possible cooperation in finitely repeated prisoner's dilemma game. The source of cooperation was some asymmetries of types of players. Andreoni and Miller (1993) conducted a series of prisoner's dilemma experiment to confirm the prediction by Kreps et al. (1982), and found that subjects' beliefs that their opponent is altruistic increase reputation building and therefore they were more cooperative than subjects in a repeated single-shot game[3]. However, the average cooperation scarcely exceeded more than 60%. Bereby-Meyer and Roth (2006) reported that noisy payoffs reduced cooperation in repeated game although they increased cooperation in one-shot game.

The second approach is to introduce a punishment strategy into the dilemma game, or the public good provision game. Fehr and Gächter (2002) introduced costly punishment in a public good provision experiment, and observed that cooperation (about 70%) with punishment is higher than that (about 30%) without punishment[4]. Hauert et al. (2007) set up an evolutionary dynamic model to understand how altruistic punishment is evolved.

---

[1] Albert Tucker (1950) is the godfather of this game. See also Flood (1952) and Chapter 6 of Poundstone (1992). As the beginning citation of this paper shows, Hume also noticed the nature of the problem as work sharing incentive problem.
[2] See Roth (1995) for an overview of experiments.
[3] Gächter and Thöni (2005) confirmed that knowing other subjects who are cooperative made subjects cooperative in a public good provision experiment.
[4] Gächter et al. (2008) conducted experiments with 50 rounds and stressed the importance of long-run benefit s of punishment.

The third approach is to introduce one more stage to the dilemma game. Andreoni and Varian (1999) and Charness, Fréchette and Qin (2007) set up a stage where subjects can reward the other subject conditional upon cooperation *before* the prisoner's dilemma game stage. The cooperation ratio was about 50-70% in this design. Banks, Plott and Porter (1988) introduced a voting stage *after* the dilemma game, and observed xx% of cooperation.

Our approach belongs to the third one. We do not aim at clarifying the human nature directly such as the evolution of cooperation through altruistic punishment in the second approach, but rather at designing institutions where both choose cooperation assuming the behavioral principle that appeared in Hume's quotation. That is, finding devices or mechanisms to make subjects cooperate is our main concern with even absolutely selfish subjects[5]. Furthermore, we also restrict ourselves to the mechanisms that are compatible with our social or legal systems. For example, we impose not using *direct* punishment (or reward) since *personal* punishment is usually prohibited in our modern societies or legal systems.

Under the above constraint, we introduce the approval stage after the prisoner's dilemma. After the dilemma stage, each subject can approve or reject the other choice of the strategy in the first stage. There are many ways to design it, we employ the following simple way in this paper: if both approve the other strategy, the outcome is the one with which both choose in the first stage, and if either one rejects it, the outcome is the one with which both defect in the first stage.

The subgame perfect equilibria of this two stage game have the outcomes where both are cooperative and both are defective. However, the all pairs of weakly evolutionarily stable strategies coincide with the subgame perfect equilibria where both are cooperative. That is, cooperative outcome cannot be implemented by the subgame perfect equilibria, but can be implemented by weakly evolutionarily stable strategy equilibria.

Therefore, our experimental task is to find subjects' behavioral interaction which theoretical suggestion is compatible with. In our experimental design, we aim at constructing the environment as bleak as possible for cooperation. In order to avoid possible learning or building-up reputation, no subject ever met another subject more than once, called the complete stranger design[6]. Furthermore, each subject could not identify where the other subject was located in the lab. As usual in this type of experiment, no talking was allowed.

---

[5] There is quite a number of interesting research papers focusing upon non-selfish behavioral or framing effects. For example, Liberman, Samuels and Ross (2004) investigated wording effect of the game such as the "Wall Street Game" or the "Community Game."

[6] Duffy and Ochs (2009) reported that random matching treatment in a repeated Prisoner's Dilemma game failed to generate cooperative norm contrary to a theoretical prediction by Kandori (1992).

Our observation is rather striking. We observed 100% cooperation in the session of prisoner's dilemma game with approval stage with 19 periods, and 7.9% cooperation in the session of the game without the approval stage. This supports the weakly evolutionarily stable strategy implementation.

Although real world applications are beyond the scope of the current paper, 100% cooperation from the very beginning is an important feature since we cannot repeat decisions in dilemma situations of many instances including international negotiations. In addition to that, no decay toward the end period was also an important and distinctive feature.

The organization of the paper is as follows. Section 2 explains the approval stage after the prisoner's dilemma stage. Section 3 is to identify the subgame perfect equilibria of the two stage game. Section 4 is for evolutionarily stable strategies of the game. Section 5 consider various possibility of implementation. Section 6 describes experimental procedures and section 7 is for experimental results. Section 8 discusses related results and future research.

2. Prisoner's Dilemma with Approval Stage

The prisoner's dilemma game with approval stage consists of two stages. In the first stage, subjects 1 and 2 play a usual prisoner's dilemma game such as Figure 1. Both players must choose either cooperation (or *C*) or defection (or *D*) simultaneously. We call *C* and *D* *outcomes*[7]. There might be many ways to interpret the matrix in Figure 1, but a typical interpretation in public economics is the payoff matrix of the voluntary contribution mechanism in the provision of a public good. Each subject has ten dollars (or initial endowment w) at the beginning, and (s)he must decide whether (s)he contributes all ten dollars (or cooperation) or nothing (or defection). The sum of the contribution is multiplied by $\alpha \in (0,1)$, that is 0.7 in the following example, and the benefit goes to both of them, which expresses non-rivalness of the public good. If both contribute, then the benefit of each subject is (10+10)x0.7=14. If either one of them contributes, contributor's benefit is 10x0.7=7, and non-contributor's benefit is 10+7=17 since (s)he has 10 dollars at hand. Therefore, the payoff matrix in Figure 1 keeps this linear structure. Of course, non-contribution (or *D*) is the dominant strategy.[8] Bold and italic parts show the equilibrium payoff in Figure 1.

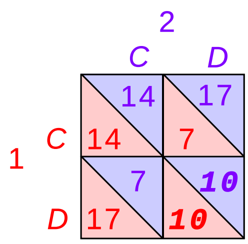


Figure 1. Prisoner's dilemma game.

Consider now the second stage as in Figure 2. Knowing the outcome of the first stage, each subject must either approve the outcome choice of the other subject (or *y*) or disapprove it (or *n*) simultaneously. Ellipses show information sets. The upper (lower) number at the bottom of the game tree show subject 1's (2's) payoff respectively.

Although there are many ways to connect the approval decisions to the outcomes, we choose the following simple way in this experiment: if both approve the outcome choices in the first stage, then the payoff is what they choose in the first stage. Otherwise, the payoff is (10,10) that corresponds to the outcome (*D*,*D*). In the context of public good provision, when both or either one of them disapproves the strategy choice of the other, the public good will not be provided and hence the money is simply return to the

[7] We reserve "strategy" for the two stage game in the following.
[8] In the experiment, we used payoff numbers that are 100 times of the numbers in Figure 2.

contributor(s). The prisoner's dilemma game with approval stage in Figure 2 is abbreviated as *PDAS*.

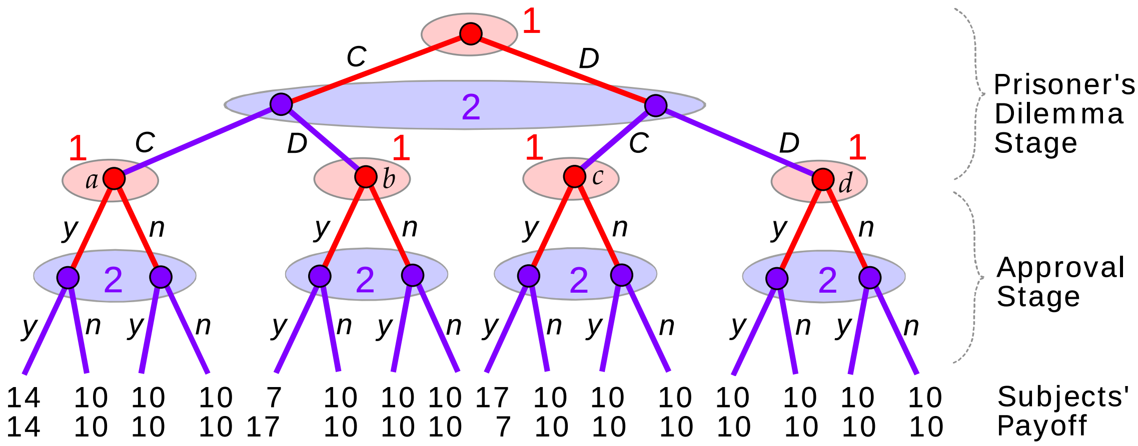


Figure 2. Prisoner's dilemma game with approval stage.

3. Subgame Perfect Equilibria of Prisoner's Dilemma Game with Approval Stage

Since each information set has two alternatives, and there are ten information sets, the total number of possible strategy profiles is 1024 (= 2^{10}). Consider four subgames in the approval stage. Let us take a look at the subgame whose starting node is *a* in Figure 2. As shown in Figure 3, subgame *a* has two Nash equilibria (*y*, *y*) and (*n*, *n*). Similarly, subgame *b* has two Nash equilibria (*n*, *y*) and (*n*, *n*), subgame *c* has two Nash equilibria (*y*, *n*) and (*n*, *n*), and subgame *d* has four Nash equilibria (*y*, *y*), (*y*, *n*). (*n*, *y*) and (*n*, *n*).

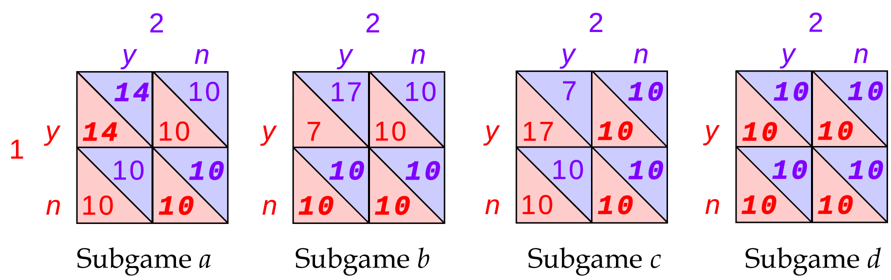
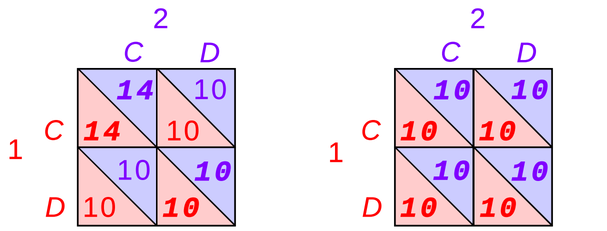


Figure 3. Four subgames in the second stage.

Given these four types of subgame Nash equilibria, consider the first stage. Since the payoff of all subgames other than subgame *a* is (10,10) in equlibrium, consider two cases (*y*, *y*) and (*n*, *n*) in subgame *a*. If it is (*y*, *y*) in subgame *a*, there are two Nash equilibria (*C*, *C*) and (*D*, *D*) (see Figure 4-(i)). Since each equilibrium has 16 cases (i.e., two Nash equilibria in subgame *b*, two in subgame *c*, and four in subgame *d*), there are 32 subgame

Nash equilibria in this case. On the other hand, if it is (*n*, *n*) in subgame *a*, there are four Nash equilibria (*C*, *C*) and (*C*, *D*), (*D*, *C*) and (*D*, *D*) (see Figure 4-(ii)). Since each equilibrium has 16 cases, we have 64 subgame Nash equilibria in this case. In total, there are 96 subgame perfect Nash equilibria.



(i) (*y*, *y*) in subgame *a* (ii) (*n*, *n*) in subgame *a*

Figure 4. The first stage in the backward induction.

Consider the subgame equilibrium paths in Figure 2. Fix (*y*, *y*) in the second stage at subgame *a*. Then (C, *C*, *y*, *y*)[9] (16 cases), (*D*, *D*, *y*, *y*) (4 cases), (*D*, *D*, *y*, *n*) (4 cases), (*D*, *D*, *n*, *y*) (4 cases), and (*D*, *D*, *n*, *n*) (4 cases). Fix (*n*, *n*) in the second stage at subgame *a*. Then (*C*, *C*, *n*, *n*) (16 cases), (*C*, *D*, *n*, *y*) (8 cases), (*C*, *D*, *n*, *n*) (8 cases), (*D*, *C*, *y*, *n*) (8 cases), (*D*, *C*, *n*, *n*) (8 cases), (*D*, *D*, *y*, *y*) (4 cases), (*D*, *D*, *y*, *n*) (4 cases), (*D*, *D*, *n*, *y*) (4 cases), and (*D*, *D*, *n*, *n*) (4 cases). Summarizing the above facts, we have,

Property 1. *In the prisoner's dilemma game with approval stage, we have*
(i) *96 subgame perfect equilibria out of 1024 possible strategy profiles;*
(ii) *the subgame perfect equilibrium paths are* (C, C, *y*, *y*), (D, D, *y*, *y*), (D, D, *y*, *n*), (D, D, *n*, *y*), (D, D, *n*, *n*), (C, C, *n*, *n*), (C, D, *n*, *y*), (C, D, *n*, *n*), (D, C, *y*, *n*), *and* (D, C, *n*, *n*); *and*
(iii) *the payoff of 16 subgame perfect equilibria is* (14, 14) *on the path* (C, C, *y*, *y*) *and the payoff of the rest is* (10, 10).

Let us define subject *i*'s strategy as $s_i = (E_i, s_i^{CC}, s_i^{CD}, s_i^{DC}, s_i^{DD})$ where E_i is *i*'s choice between *C* and *D* in the prisoner's dilemma stage, and s_i^{AB} is *i*'s choice between *y* and *n* in the approval stage when subject *i* chooses *A* and subject *j* chooses *B* in the prisoner's dilemma stage[10]. $P(s_1, s_2)$ is the *path* with (s_1, s_2). Then we have,

[9] A *path* is (subject 1's choice between *C* and *D*, subject 2' choice between *C* and *D*, subject 1's choice between *y* and *n*, subject 2's choice between *y* and *n*).)

[10] Another way to define *i*'s strategy is use the choices at subgames such as $s_i = (E_i, s_i^a, s_i^b, s_i^c, s_i^d)$. Since the current way can take advantage of symmetry of *PDAS*, we did not use this definition.

Property 2. *16 strategy profiles where the payoff of subgame perfect equilibrium is (14,14) are* $(s_1, s_2) = ((C, y, n, \cdot, \cdot), (C, y, n, \cdot, \cdot))$ *where "* $\cdot$ *" indicates either y or n.*

A notable characteristic is that the Prisoner's dilemma game with approval stage has its Pareto efficient payoff, i.e., (14, 14), as the payoff of the subgame perfect equilibrium.[11]

4. Evolutionarily Stable Strategies of Prisoner's Dilemma Game with Approval Stage

The payoff of subgame perfect equilibria is either (14,14) or (10,10). In what follows, we will show that 16 subgame perfect equilibrium strategy profiles whose payoff is (14,14) in Property 2 are generated by four weakly evolutionarily stable strategies. Let $v(s,t)$ be the payoff of subject 1 when the strategy profile is (s,t). Due to the symmetry of the payoff structure, subject 2's payoff at (s,t) is $v(t,s)$.

Definition 1. A strategy t is *weakly evolutionarily stable strategy* (*or weak ESS*) if and only if for all $t' \neq t$,
(i) $v(t,t) \geq v(t',t)$ and
(ii) $v(t,t) = v(t',t)$ implies $v(t,t') \geq v(t',t')$.

If the weak inequality in (ii) becomes strict, then t is called *evolutionarily stable strategy* (or *ESS*).

Property 3. $(C, y, n, \cdot, \cdot)$ *is a weakly evolutionary stable strategy where "* $\cdot$ *" indicates either y or n.*

Proof. The following four cases cover all strategies.
Case 1. $t = (D, \cdot, \cdot, \cdot, \cdot)$ is not weakly *ESS*.
Let $t' = (C, y, n, n, \cdot)$. Since $P(t,t) = (D, D, \cdot, \cdot)$, $P(t',t) = (C, D, n, \cdot)$, $P(t,t') = (D, C, \cdot, n)$ and $P(t',t') = (C, C, y, y)$, we have $v(t,t) = v(t',t) = v(t,t') = 10$ and $v(t',t') = 14$. Therefore, t is not weakly *ESS*.
Case 2. $t = (C, n, \cdot, \cdot, \cdot)$ is not weakly *ESS*.
Let $t' = (C, y, \cdot, \cdot, \cdot)$. Since $P(t,t) = (C, C, n, n)$, $P(t',t) = (C, C, y, n)$, $P(t,t') = (C, C, n, y)$ and $P(t',t') = (C, C, y, y)$, we have $v(t,t) = v(t',t) = v(t,t') = 10$ and $v(t',t') = 14$. Therefore, t is not weakly *ESS*.

[11] The set of Nash equilibria of *PDAS* is strictly larger than the set of subgame perfect equilibria of *PDAS*. For example, $(s_1, s_2) = ((D, n, n, n, n), (D, n, y, n, n))$ is a Nash equilibrium, but not a subgame perfect equilibrium.

Case 3. $t=(C,y,y,\cdot,\cdot)$ is not weakly *ESS*.
Let $t'=(D,\cdot,\cdot,y,\cdot)$. Since $P(t,t)=(C,C,y,y)$ and $P(t',t)=(D,C,y,y)$, we have $v(t,t)=14<v(t',t)=17$. Therefore, *t* is not weakly *ESS*.
Case 4. $t=(C,y,n,\cdot,\cdot)$ is weakly *ESS*.
Since $P(t,t)=(C,C,y,y)$, $v(t,t)=14$.
(i) If $t'=(D,\cdot,\cdot,\cdot,\cdot)$, $v(t',t)=10$ because $P(t',t)=(D,C,\cdot,y)$. Therefore, $v(t,t)=14>v(t',t)=10$.
(ii) If $t'=(C,n,\cdot,\cdot,\cdot)$, $v(t',t)=10$ because $P(t',t)=(C,C,n,y)$. Therefore, $v(t,t)=14>v(t',t)=10$.
(iii) If $t'=(C,y,\cdot,\cdot,\cdot)$ with $t'\neq t$, $P(t',t)=P(t,t')=P(t',t')=(C,C,y,y)$. Therefore, $v(t',t)=v(t,t')=v(t',t')=14$. Hence, $v(t,t)=v(t',t)$ and $v(t,t')=v(t',t')$.
These cases show that *t* is weakly *ESS*. □

Combining Properties 2 and 3, we have,

Property 4. *All 16 weakly evolutionarily stable strategy profiles are exactly the same as the 16 subgame perfect equilibrium strategy profiles whose payoff is* (14,14).

Define that a strategy set *S* is the *evolutionarily stable strategy* (*ESS*) *set* if and only if for all $t\in S$ and $t'\notin S$, (i) $v(t,t)\geq v(t',t)$ and (ii) $v(t,t)=v(t',t)$ implies $v(t,t')>v(t',t')$. Let *WESS* be the set of weakly *ESS*. That is, *WESS* = {$(C,y,n,\cdot,\cdot)$ where "$\cdot$" = "y or n"}. We can also define a subgame perfect *WESS* replacing (i) in Defintion 1 with (i') (*t*,*t*) is a subgame perfect equilibrium . Immediate results from the proof of Property 4 are

Property 5. *In the prisoner's dilemma game with approval stage, we have*
(i) *No evolutionarily stable strategy exists;*
(ii) $v(s,t)=v(t,s)$ = 14 *for all* $t,s\in$ *WESS; and*
(iii) *WESS is the evolutionarily stable strategy set.*
(iv) *WESS = subgame pefect WESS.*
(v) *Weak ESS is not a dominant strategy.*

Proof. (i) It is sufficient to note that $t'=(C,y,\cdot,\cdot,\cdot)$ is not an *ESS* shown in Case 4 in Property 3. (ii), (ii) and (iv) are also trivial. Choose a weak ESS $t=(C,y,n,\cdot,\cdot)$ and choose $t'=(C,y,y,\cdot,\cdot)$. Since $P(t,t')=(C,C,y,y)$, $v(t,t')=14$. If subject 1 changes the strategy from *t* to $t''=(D,\cdot,\cdot,y,\cdot)$, then $P(t'',t')=(D,C,y,y)$. Then $v(t'',t')=17$, and hence *t* is not a dominant strategy. □

5. Implementability

Let $u(\cdot,\cdot)$ be a payoff function defined on the outcome space $A=\{C,D\}\times\{C,D\}$ and generated from $w>0$ and $\alpha\in(0,1)$ in section 1. Let

$U=\{u: u \text{ is generated from some } w \text{ and some } \alpha\in(0,1)\}$.

Then define a social choice correspondence $f: U \twoheadrightarrow A$ by

$f(u)=$ the set of maximizers of $\{2u(C,C), u(C,D)+u(D,C), 2u(D,D)\}$.

Then, by construction, *f* is singleton and $f(u)=\{(C,C)\}$ for all $u\in U$. In the usual prisoner's dilemma case, the strategy (or outcome) space for each subject is {*C,D*} and the game form is an identity function $I: A\to A$ where $(A,B)=I(A,B)$. Using the dominant strategy and writing the set of dominant strategy equilibria as D_I, we have $I\cdot D_I(u)=(D,D)\neq(C,C)$, that is, *f* cannot be implemented by dominant strategy equilibria.

Let *S* be the set of all possible strategy profiles of the prisoner's dilemma game with approval stage, and let *g* be the game form defined in Figure 2. Write $SPE_g(u)$ as the set of subgame perfect equilibria using the game form under *u*. Then $g\cdot SPE_g(u)=\{(C,C),(D,D)\}$ $\neq\{(C,C)\}$, and hence *f* cannot implemented in subgame perfect equilibrium with this game form. However, writing $WESS_g$ as the set of weakly *ESS* pairs, we have $g\cdot WESS_g(u)=f(u)$ for all possible *u*. That is, *f* is implemented by *g* in weakly *ESS*[12]. Obviously, *f* cannot be implemented by *g* in *ESS* due to Property 5. That is,

Property 6.

(i) *Cooperation cannot be attained in the prisoner's dilemma game in dominant strategy.*

(ii) *The game form designed for the prisoner's dilemma game with approval stage cannot implement cooperation in subgame perfect equilibria.*

(iii) *The game form designed for the prisoner's dilemma game with approval stage implements cooperation in weakly evolutionarily stable strategy equilibria* (*or the game form designed for the prisoner's dilemma game with approval stage implements cooperation in the evolutionarily stable strategy set.*)

(iv) *The game form designed for the prisoner's dilemma game with approval stage cannot implement cooperation in evolutionarily stable strategy equilibria.*

[12] Nakamaru, Okano, Saijo and Yamato (2010), as a companion paper to the current paper, show that the prisoner's dilemma game with approval stage implements the Pareto optimal outcome in an evolutional dynamics model.

Property 6 apparently demands experimental evidences which ones are supported especially between (ii) and (iii) when the approval stage is introduced.

6. Experimental Procedures

We conducted the experiment for a day in November 2009 and a day in March 2010 at the Economics Department Computer Laboratory of Osaka University. We had two sessions in November 2009: one of them is prisoner's dilemma session (hereafter *PD*), and the other is *PDAS* session. Two other sessions will be explained later.

Let us explain the *PD* and *PDAS* sessions. Twenty subjects participated in each session, and hence the total number of different subjects was forty. We recruited these subjects by campus-wide advertisement[13]. They were told that there would be an opportunity to earn money in a research experiment. Communication among the subjects was prohibited, and we declared that the experiment would be stopped if it were observed. This never happened. The experiment required approximately 75 minutes to complete in the *PD* session and 115 minutes in the *PDAS* session.

The experimental procedure is as follows. We made ten pairs out of twenty subjects seated at computer terminals in each session. The pairings were anonymous and were determined in advance so as not to pair the same two subjects more than once. Since most of the previous studies such as Andreoni and Varian (1999), Cooper et al. (1996), Charness, Fréchette and Qin (2007) employed random matching among 4 to 8 subjects, the repetition necessarily entails of pairings of the same two subjects. Therefore, this "complete" strangers design might reduce possibility of cooperation among subjects comparing with the previous designs. 19 rounds were conducted in each session. Each subject received an experimental procedure sheet, instruction sheet, and record sheet. The instruction was read loudly by the same experimenter.

Let us explain the *PDAS* session. After the instruction, round one began. Each subject selected either *A* (cooperation) or *B* (defection) in the choice stage, and then inputted the choice into a computer and also filled in it on the record sheet. After that, each subject wrote the choice reason in a small box on the record sheet by hand[14]. Then the next was the decision stage. Knowing the other's choice, each subject chose either "accept" or

---

[13] The affiliation distribution of forty subjects was as follows: Engineering Science (4), Engineering (5), Law (4), Economics (3), Pharmaceutical Sciences (1), Foreign Studies (1) and Human Sciences (1) in the *PDAS* experiment where numbers in parentheses are the numbers of subjects. Engineering Science (7), Engineering (4), Economics (2), Letters (2), Law (1), Pharmaceutical Sciences (1), Foreign Studies (1), Human Sciences (1), and Science (1) in the *PD* experiment. The numbers include both undergraduate and graduate students, average ages are 22.1 in *PDAS* and 22.5 in *PD*, and the numbers of females are 4 in *PDAS* and 3 in *PD*.

[14] We used the z-Tree program developed by Fishbacher (2007).

"reject" the other's choice, and then inputted the decision into a computer and also filled in it on the record sheet. After that, each subject wrote the reason in a small box by hand. Once every subject finished the task, each subject could see "your decision," "the other's decision," "your choice," "the other's choice," "your points," and "the other's points" on the computer screen. However, neither the choices nor the decisions in pairs other than "your" own were shown on the computer screen. This ended one round. The session without the decision stage became the *PS* session. After finishing all 19 rounds, every subject filled in questionnaire sheet. Before the real rounds started, we allowed the subjects five minutes to examine the payoff table and to consider their strategies[15].

7. Experimental Results

Let us take a look at the *PDAS* session first. All twenty subjects chose cooperative strategy in the choice (or dilemma) stage, and then chose approval in the decision (or approval) stage in all nineteen rounds. See also Figure 5.

In the *PD* session, subject 5 chose cooperation in periods 1, 2 and 3, subject 10 chose it in periods 3 and 8, subject 13 chose it in periods 1 and 11, subject 16 chose it in periods 2, 6, 9 and 17, and subject 17 chose it in all periods. In total, the number of cooperation choice is 30 out of 380, which is 7.9%, and 11 percent for the first five periods declining to 6 percent for the last five periods. No (*C*, *C*) was observed among 190 pairs. The cooperation rate in our experiment is slightly lower than the previous experiments. For example, Roth and Murningham (1978) find 10.1 percent cooperation, Cooper et al. (1996) find 20 percent, and Andreoni and Miller (1998) find 18 percent. Hence, our subjects are more in line with game-theoretic logic such as adopting dominant strategy and Nash equilibrium strategy.

In order to test the null hypothesis that the cooperation rates are the same between two sessions, we conduct the chi-square test of equality of two distributions. Let p_X and p_Y denote the true cooperation rate in sessions *X* and *Y*, C_X and C_Y the number of subjects who choose cooperation in sessions *X* and *Y*, D_X and D_Y the number of subjects who choose defection in sessions *X* and *Y*, and N_X and N_Y the number of observations in sessions *X* and *Y*. In our experiment $N = N_X = N_Y = 380$. The null hypothesis is $p_X = p_Y = p$. When *p* is replaced by its maximum likelihood estimate $p^* = \dfrac{C_X + C_Y}{N_X + N_Y}$, then the test statistic

[15] Every subject received \$61.65 (\$1=86.3 yen) in *PDAS*, and the average payoff per subject was \$45.41 in *PD* where the maximum payoff was \$48.90, and the minimum payoff was \$30.82.

$$T = \frac{(C_X - Np^*)^2}{Np^*} + \frac{(D_X - N(1-p^*))^2}{N(1-p^*)} + \frac{(C_Y - Np^*)^2}{Np^*} + \frac{(D_Y - N(1-p^*))^2}{N(1-p^*)} \qquad (1)$$

is distributed asymptotically as a chi-square with 1 degree of freedom. The chi-square test clearly rejects the null hypothesis that the cooperation rate in the *PDAS* session is the same as the one in the *PD* session. Test statistic is 648.78 whose p-value is 0.000. Hence, approval mechanism has strong effect making subjects more cooperative.

Observation 1.
(i) *In the prisoner's dilemma game with approval stage session, all twenty subjects chose cooperative strategy in the dilemma stage, and then approved the other choice in the approval stage in all nineteen rounds.*
(ii) *In the prisoner's dilemma game only session, the number of cooperation choice is 30 out of 380 (7.9%), and no* (*C, C*) *was observed among 190 pairs.*
(iii) *The cooperation ratio in the prisoner's dilemma game with approval stage session is significantly different from the one in the prisoner's dilemma game only session.*

In order to understand the framing effect, we also conducted the *PD* game with unanimous voting (*PDUV*) session. The experimental procedure is exactly the same as in *PDAS* session except for the unanimous voting stage. Each subject must vote for the outcome of the *PD* stage. If both approve the strategy choices in the *PD* stage, then the outcome is what they choose in the *PD* stage. Otherwise, the outcome is (10,10). That is, *PDAS* and *PDUV* are mathematically equivalent, but not *cognitively*. For example, (*C,D*) is observed in the *PD* stage. In *PDAS*, for example, consider the case where subject 1 does not approve subject 2's choice *D*, but in *PDUV*, subject 1 must consider to vote on the outcome (*C,D*). In this sense, comparing *PDAS* with *PDUV* is to understand the framing effect.

Let us describe the results of the *PDUV* session. Overall, the cooperation rate is 98.2 percent. For the early periods, some subjects chose the defection, at period 3 full cooperation was achieved for the first time, and after 11 periods all subjects chose the cooperative strategy. The chi-square test rejects the null hypothes is that the cooperation rate in the *PDUV* session is the same as the one in the *PD* session. Test statistic is 621.48 whose p-value is 0.000. Hence, the unanimous voting also has strong effect making subjects more cooperative.

Next, we examine whether the framing effect. The chi-square test rejects the null hypothesis that the cooperation rate in the *PDAS* session is the same as the one in the *PDUV* session at the 1 percent significant level. Test statistic is 7.065 whose p-value is 0.008. Hence, the framing effect is significantly present although 100% cooperation in the *PDAS* session and 98.2% coopeartion in the *PDUV* session are not seemingly different so much.

Observation 2.

(i) *In the prisoner's dilemma game with unanimous voting, the cooperation rate is 98.2% and the defection occurred in the first few rounds.*

(ii) *The cooperation ratio in the prisoner's dilemma game with unanimous voting is significantly different from the ones in the prisoner's dilemma game only session and the prisoner's dilemma game with unanimous voting.*

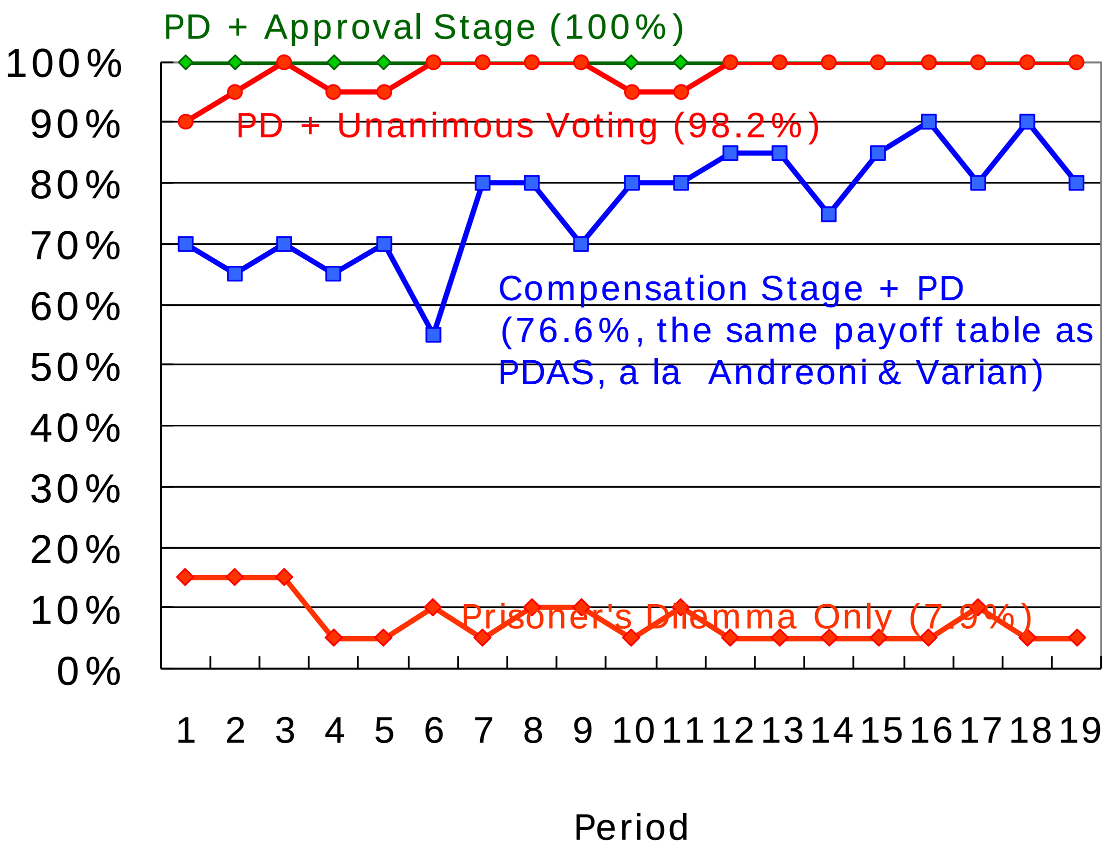


Figure 5. Cooperation ratio of two sessions.

Finally, let us compare our results with two-stage game experiments introduced by Andreoni and Varian (1999). They added a stage called the *compensation stage* (*CS*) where each subject can offer to pay the other subject to cooperate *before* the *PD* stage. Then they show that the Pareto efficient outcome is the unique subgame perfect equilibrium in their asymmetric payoff table. Eight subjects formed four groups and the matching was random. They played a usual *PD* game for the first 15 periods, and then played the two stage game from 16 to 40 periods. The cooperation ratio of the former was 25.8% and the latter was 50.5%.

We used the *PD* game in Figure 1 rather than their asymmetric game. The unique subgame perfect equilibrium is that both offer three in the *CS*, and choose cooperation in the *PD* stage. Due to discreteness of strategies, the offers are either three or four in the CS. The experimental design is the same as *PDAS* where the *CS* first and then *PD* stage second. Twenty subjects repeated *CSPD* nineteen times. Overall, 76.6 percent of moves are cooperative, 68 percent for the first five periods increasing to 85 percent for the last five periods. We ran an ordinary least-squares regression of the cooperation rate on an intercept and the period, i.e.,

$$CooperationRate_t = \alpha + \beta t + \varepsilon_t, \quad t = 1, \cdots, 19.$$

The result indicates that the *OLS* estimate of the coefficient of the period is significantly greater than zero at the 1 percent significant level. Hence, the cooperation rate significantly increases as time passes, though it does not reach the full cooperation at period 19. The chi-square test rejects the null hypothesis that the cooperation rate in the *CSPD* session is the same as the one in the *PD* session. Test statistic is 367.39 whose *p*-value is 0.000. Hence, the compensation stage has the effect making subjects more cooperative. The chi-square test rejects the null hypothesis that the cooperation rate in the *CSPD* session is the same as those in the *PDAS* and *PDUV* sessions. In the test of *CSPD* sesssion versus *PDAS* session, test statistic is 100.80 whose *p*-value is 0.000. This indicates that the compensation stage is also far from 100% successful. In the test of the *CSPD* sesssion versus *PDAS* session, test statistic is 80.17 whose *p*-value is 0.000.

In the subgame perfect equilibrium, players should offer 300 or 400. We see that the actual behavior is consistent with this prediction. Overall, the average side payment is 356.58. In each of 19 periods, subjects offer their side payment between 300 and 400 on average. The minimum average side payment is 325 in period 6, and the maximum average side payment is 395 in periods 8 and 11.

Observation 3.

(i) *In the prisoner's dilemma game with the compensation stage,76.6 percent of moves are cooperative: 68 percent for the first five periods and 85 percent for the last five periods, and the cooperation rate significantly increases as round passes.*

(ii) *The cooperation rate in the prisoner's dilemma game with the compensation stage session is significantly higher than that of the prisoner's dilemma only session, and it is far from 100%.*

successful.

The cooperation ratio in the prisoner's dilemma game with the compensation stage session is significantly different from the ones in the prisoner's dilemma game only session and the prisoner's dilemma game with unanimous voting..

(iii) *The average side payment is 356. 58 with 325 as the minimum and 395 as the maximum where the subgame perfect side payment is between 300 and 400.*

Let us now consider how subjects respond to the outcome in the *PD* stage in the *PDAS* and *PDUV* sessions. Tables 1 and 2 show the responses. The second column shows the frequencies with which the respective outcomes in the *PD* stage are observed. The outcome (*X, Y*) (*X, Y* = *C, D*) means that in the *PD* stage the own choice is *X* and the other's choice is *Y*. The third and fourth columns show the frequencies with which subjects choose 'accept' and 'reject' the other's strategy respectively. In the *PDAS* session, all subjects choose cooperation in the choice stage, and then accept the other's strategy as shown in Table 1.

Outcome	Frequency	Accept	Reject
(*C, C*)	380	380	0
(*C, D*)	0	-	-
(*D, C*)	0	-	-
(*D, D*)	0	-	-

Table 1: The *PDAS* session

Outcome	Frequency	Accept	Reject
(*C, C*)	366	365	1
(*C, D*)	7	0	7
(*D, C*)	7	7	0
(*D, D*)	0	-	-

Table 2: The *PDUV* session

In the *PDUV* session, only one subject chose rejection when the outcome in the first stage was (*C, C*). In the questionaire after the experiment this subject wrote that he got bored with the succession of (*C, C, Accept, Accept*) outcomes, so he chose the rejection. This subject also chose defection in the first stage in periods 4, 5, 10 and 11. Another two subjects chose defection in the *PD* stage. One chose defectioin only in period 1. Looking at the questionaire, it seems that this subject did not consider the game deeply enough.

Another one chose defection in periods 1 and 2. Looking at the questionaire, this subject thought that there might be some subjects who misunderstood with the game at the beginning of the experiment, and might accept his defection. When the own choice is *C* and the other's choice is *D* (this occurs 7 times), subjects always choose rejection. When the own choice is *D* and the other's choice is *C*, subjects always choose acceptance.

8. Discussion

We found that our approval rule promotes cooperation significantly in prisoner's dilemma game. This experimental evidence supports that the game form designed for the prisoner's dilemma game with the approval stage implements cooperation in the *ESS* set.

The approval rule looks similar to the unanimous rule, and both have the same outcomes. However, the framework of approval rules is more general than that of simple voting rules. Consider, for example, an outcome (*C, C, n, y*) where both choose cooperation, and subject 1 does not approve subject 2's decision. If this is the case, set up a rule in which subject 1 must contribute 10. In other words, subject 1 says, "thank you very much for your cooperation, but I would like to contribute 10 and please do not do that." In this sense, this is a generous rule that cannot be generated from a usual voting scheme that just counts the number of "*C*" or "*y*." Actually, there are exactly six approval rules where the subgame perfect equilibrium payoff is (14,14)[16].

Since there are several rules having (14,14) as a subgame perfect equilibrium payoff, investigating the experimental performances of them is also an interesting research agenda. Furthermore, since the approval rule in this paper and the unanimous rule have the same outcome, it is important to find the framing differences between them.

Although our theoretical justification comes from the weakly *ESS* set, full cooperation in our experiment started from round one. This indicates that the cooperation does not come from some learning process through rounds, but it comes from instantaneous understanding of the game from the very beginning. That is, how subjects understand the game and its *best* strategies will be an important future agenda.

Our payoff table is symmetric between subjects 1 and 2. Andreoni and Varian (1999) and Charness, Fréchette and Qin (2007) used asymmetric payoff tables and observed some interaction between efficiency and equity among subjects. Whether the approval rule we employed works in environments with asymmetric payoff structure is an open question.

Banks, Plott and Porter (1988) compared the Smith auction and the voluntary contribution mechanism both with and without the second stage of the unanimity rule in

---

[16] See Okano, Saijo and Yamakawa (2010).

the provision of a public good. They used non-linear utility functions and found that the Smith auction worked well but the unanimity rule reduced the efficiency. Our approval stage approach can be extended to non-linear utility functions with many subjects.

We just conducted two sessions, and hence further replications and extensions are needed.

Further replications and modified modeling are needed.

References

Banks, Jeffrey S & Plott, Charles R & Porter, David P, 1988. "An Experimental Analysis of Unanimity in Public Goods Provision Mechanisms," *Review of Economic Studies*, Vol. 55(2), pages 301-22.

Charness, Gary, Guillaume R. Frechette and Cheng-Zhong Qin, 2007. "Endogenous transfers in the Prisoner's Dilemma game: An experimental test of cooperation and coordination," *Games and Economic Behavior*, Elsevier, vol. 60(2), pages 287-306.

Duffy, John and Jack Ochs (2009),"Cooperative Behavior and the Frequency of Social Interaction" *Games and Economic Behavior* 66 (2009), 785-812.

Fehr, Ernst and Simon Gächter, "Altruistic punishment in humans," *Nature* Vol. 415, 10 January 2002, pp.137-40.

Flood, Merrill M. "Some Experimental Games," Research Memorandum RM-789, Santa Monica, RAND Corporation, 1952.

Friedman Daniel and Ryan Opreaz, "A Continuous Dilemma," September 10, 2009.

Gächter, Simon and Christian Thöni, "Social Learning and Voluntary Cooperation among Like-Minded People," *Journal of the European Economic Association*, April–May 2005, 3(2–3), pp.303–314.

Gächter, Simon, Elke Renner, Martin Sefton,"The Long-Run Benefits of Punishment," *Science* Vol. 322, 5 December 2008, p. 1510.

Hauert, C. & Doebeli, M. (2004), "Spatial structure often inhibits the evolution of cooperation in the snowdrift game," *Nature* 428, 643–646.

Hauert, Christoph, Arne Traulsen, Hannelore Brandt, Martin A. Nowak and Karl Sigmund, "Via Freedom to Coercion: The Emergence of Costly Punishment," *Science* Vol. 316, 29 June 2007, pp. 1905-7.

Herrmann, Benedikt, Christian Thöni and Simon Gächter, "Antisocial Punishment Across Societies," *Science* Vol. 319, 7 March 2008, pp. 1362-1367.

Kandori, M., 1992. Social norms and community enforcement. *Rev. Econ. Stud.* 59, 63–80.

Liberman, V., Samuels, S.M. & Ross, L. (2004) "The name of the game: Predictive power of reputations versus situational labels in determining prisoner's dilemma game moves," *Personality and Social Psychology Bulletin* 30:1175-1185.

Poundstone, William, *Prisoner's Dilemma*, Anchor Books, 1992.

Yoella, Bereby-Meyer and Alvin E. Roth, "Learning in Noisy Games: Partial Reinforcement and the Sustainability of Cooperation," *American Economic Review*, 96, 4, September, 2006, 1029-1042.

Use of Economic Valuation in the City of Calgary Biodiversity Conservation Strategy Program – Nose Hill Natural Environment Park

Presented at

First Congress of East Asian Association of Environmental and Natural Resource Economics

Prepared by

Mona Keffer
Natural Area Project Coordinator

THE CITY OF
CALGARY
PARKS

July 9, 2010

Table of Contents

List of Maps

List of Tables

List of Figures

Abstract

This paper explains how economic valuation of biodiversity could help natural resource managers and policy makers to protect and conserve habitats such as native grasslands within the City of Calgary. Various economic valuation methods were explored to demonstrate the importance and long-term value of native grasslands to society. The project also evaluated the cost – benefit outcomes of native grassland conservation to one-time loss of opportunity cost through land sales and land conversion to urban land uses. The project focused on Nose Hill in Calgary, Alberta, Canada as a representative expansive native grassland communities. Nose Hill (1,129 hectares) is one of the largest urban natural parks in North America.

A policy framework that helps assign a dollar value for ecological services beneficial to society would be necessary. Economic valuation is essentially a method to relate the various benefits of ecosystem goods and services and their associated costs to assigned dollar values. A number of economic valuation tools have been developed over the last two decades. The most common approach is the Total Economic Value. The approach uses three categories, namely use, non-use, and option values. The use and non-use values include direct and indirect approaches. The direct approach employs tools to gather use preference directly by using survey questionnaire, research and experiments. Whereas, the indirect approach applies tools to elicit values of the ecosystem benefit from observed market-based information. With the approach, use preference is indirectly inferred by relating the purchase of marketed goods and services. One example is travel cost.

The applicability of the travel cost approach to measure value based on the cost people are willing to pay to travel to Nose Hill Park will be further investigated. This approach uses the observed expenditures of travelling and estimates the benefit of the recreational activities. The approach will use data from the park visitation frequency, an assumed distance and the City's mileage cost to assign value of willingness to pay to travel to Nose Hill Park. The findings will be used to understand the implied value of the services provided by the park.

The analysis aims to provide a defensible rationale for protection and conservation of native grasslands through effective environmental planning.

1. Introduction

Approximately 33% of the Canadian Great Plains region occurs in Alberta. Only 10% is considered as native grassland. The remainder has been subject to land conversion activities such as agriculture, urban development and resource extraction. Calgary is built on the expansive Foothills Fescue Grassland.

The Parks department is the steward of Calgary's open space. Over the years, a number of policies and guidelines have been approved by City Council that espouses the protection and conservation of natural environment within the urban context.

Currently, Parks is embarking on a long term program aiming at the conservation of Calgary's biodiversity. Understanding the value of Calgary's biodiversity is an important step. The natural capital of biodiversity is easily understood but often not considered in land use decisions. This project attempts to explore the application of economic valuation to help protect and conserve Calgary's biodiversity as a policy rationale that can be integrated into the current Parks planning process.

Over the years, Parks has acquired approximately 7,000 ha of parks and open space through the land subdivision process. Much of this land encompassed native grassland. The majority of the parks are found along steep slopes, drainage corridors, and around lands subject to flooding. The native grasslands that occur in developable lands are at present under threat from land conversion activities. Adequate legislative tools that enable their protection and conservation are lacking. The only recourse would be purchase using public funds requiring the approval of City Council. A strong rationale would be required to demonstrate the need to protect future native grassland.

2. The City of Calgary Parks Biodiversity Strategy

The Parks department is currently developing the Biodiversity Strategy as a key policy for Natural Area Management. The premise is centered on the need to protect and conserve natural areas as a continuous open space system; applying the landscape ecology approach is applied throughout the operations and planning work units while considering the importance of ecosystem services and functions that are beneficial to Calgarians.

The Strategy aims to provide all-encompassing policy goals and strategic directions that integrate The City of Calgary's Triple Bottom Line policy that addresses community well-being; sustainable environment while supporting economy development; encouraging smart growth and mobility choices throughout the management and conservation of open space and natural environment. The Strategy is based on four major priorities:

(1) strengthening ecosystem resilience through maintenance of ecological services and function;

(2) improve the understanding of biodiversity and ecosystem services through collaboration with private industry and academia;

(3) expand on current information about Calgary's open spaces through undertaking a city wide biophysical inventory and a monitoring program; and

(4) improve legislative compliance through establishment of targets and thresholds measuring management effectiveness.

The Biodiversity Strategy Action Plan will be developed to articulate actions that will implement the vision, goals and strategic directions identified in the Biodiversity Strategy. Ultimately, the action plan will serve as a tool for Parks in the delivery of Biodiversity Strategy programs at the corporate level as well as at the local level through Environmental Education Initiatives.

3. Native Grassland Ecosystem

Grasslands are characterized as lands dominated by grasses. These landscapes were created in the Miocene and Pliocene Epochs, occurred over a period of about 25 million years. The formation of mountains ranges helps create a climate favourable to grasslands. As ancient forests receded and grasslands became more prevalent with the ranges expanded further into the landscape after the Pleistocene Ice Ages.

Grasslands can be found throughout world but Antarctica, from the tropics to the edge of the boreal forest (Coupland 1992) making up 12 % (Whittaker and Likens 1975) to 30% (Ajtay et al. 1979). The grasslands of the North American Great Plains ecoregion[1] represent about 2% of the world's terrestrial surface occupying 12.5% of North America (Bailey 1998) from the Gulf of Mexico throughout the United States and into prairie provinces of Canada.

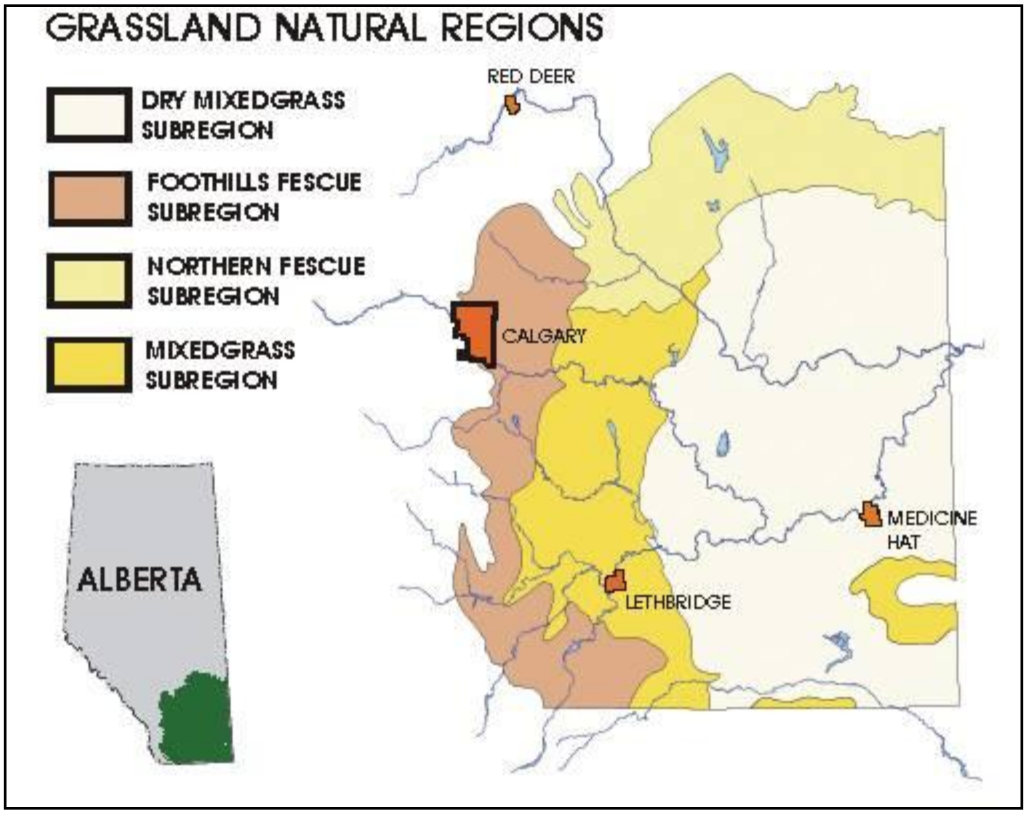
These grasslands are exposed to extreme variations of climate with hot summers and cold winters. Rainfall is moderate which greatly influences the height of grassland vegetation, with taller grasses in wetter regions. Seasonal drought and occasional fires are common and are considered to be very important to biodiversity. The soil of the temperate grasslands is chernozemic in nature, with fertile upper layers contributed by the growth and decay of deep of the above – and below- ground biomass. The decaying roots provide the structure that binds the soil together and provide a food source for living plants. The physical characteristics of the environment dictate the type of grassland ecosystem would be dominant. The seasonal drought, occasional fires, and grazing by large mammals such as bison and cattle help to prevent the establishment of

[1] Ecoregion is defined as any large portion of the Earth's surface over which the ecosystems have characteristics in common…." (Bailey 1998).

woody shrubs and trees. Cottonwoods and willows are also found in the prairies but typically gorw in river valleys in areas that are prone to flooding or areas with higher soil moisture content. A multitude of flower species are found to occur throughout grasslands.

The native grasslands in the Province of Alberta are found within the northern extent of the North American Great Plains ecoregion west to the Rocky Mountain and north into central Alberta. The region is characterised as flat to gently rolling plain interrupted by hills and bedrock outcrops. The prairies ecosystems are differentiated by climatic, soil composition and vegetation community variations. They make up the four sub-ecoregions namely Dry Mixedgrass, Northern Fescue and Foothills Fescue. The Dry Mixedgrass Subregion is most extensive, starting at the United States border north and west to the Mixedgrass and Northern Fescue Subregions. The Mixedgrass Subregion occurs generally west of the Dry Mixedgrass Subregions. The Northern Fescue and Foothills Fescue Subregions occur in narrow belts along the northern and western margins of the Dry Mixedgrass and Mixedgrass Subregions (Alberta Prairie Conservation Forum)

Figure 1 Rock outcrops in grassland landscape. Photo courtesy of Alberta Prairie conservation Forum



Map 1 Grassland Natural Regions of Alberta[2]

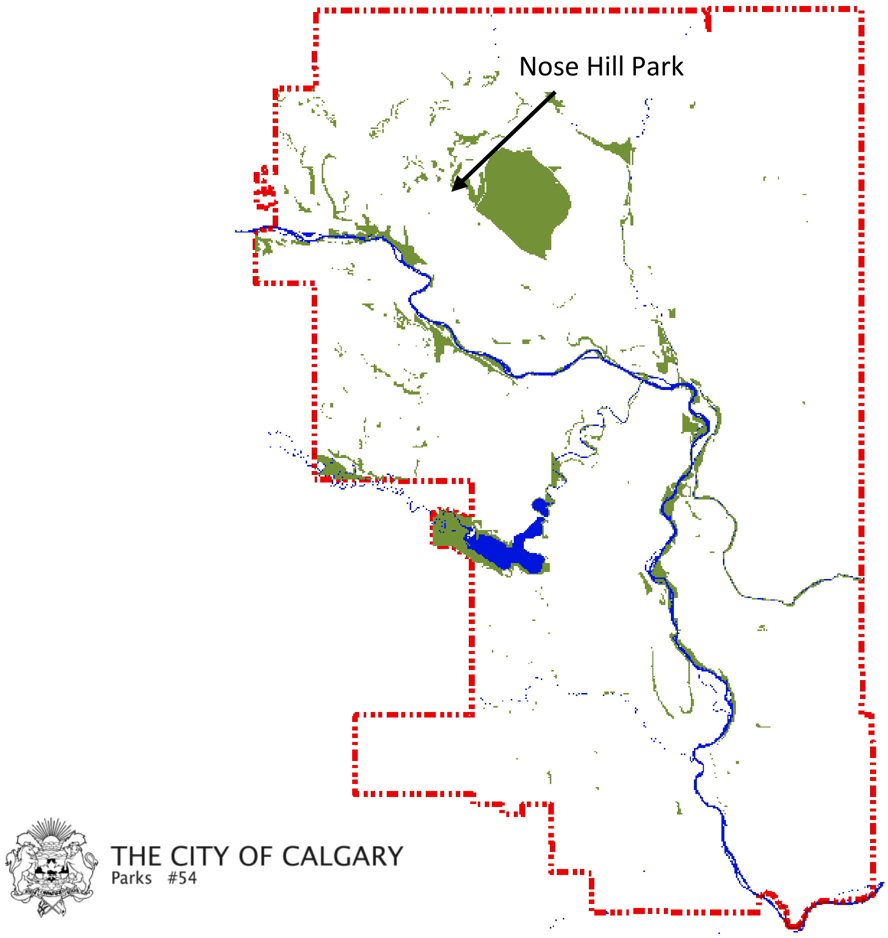
Some of the native grassland representatives include Western wheatgrass (*Agropyron smithii),* Blue grama (*Bouteloua gracilis),* June grass (*Koeleria macrantha,* Green needle grass (*Stipa viridula),* Sand reed grass (*Calamovila longifolia),* Awned wheatgrass (*Agropyron subsecundum), and* Rough fescue (*Festuca campestris).* Flowers include asters, blazing stars, coneflowers, goldenrods, sunflowers, and clovers. The typical prairie wildlife include jack rabbits, deer, mice, coyotes, foxes, skunks, badgers, blackbirds, grouses, meadowlarks, quails, sparrows, hawks, owls, snakes, grasshoppers, leafhoppers, and spiders.

3.1 Nose Hill Natural Environment Park

Nose Hill Natural Environment Park (Nose Hill Park) is located within the intersecting Subregions of the Foothills Fescue and the Aspen Parkland. The Fescue Ecoregion is characterised by the presence of the rough fescue community dominating the landscape (Achuff 1994).The Aspen Parkland Ecoregion is signified by the co-occurrence of rough fescue prairie and stands of aspen forest. Nose Hill is located in

[2] Alberta Prairie Conservation Forum, 2010.

the northwest part of the city, surrounded by 12 residential communities covering over 11 square kilometres.

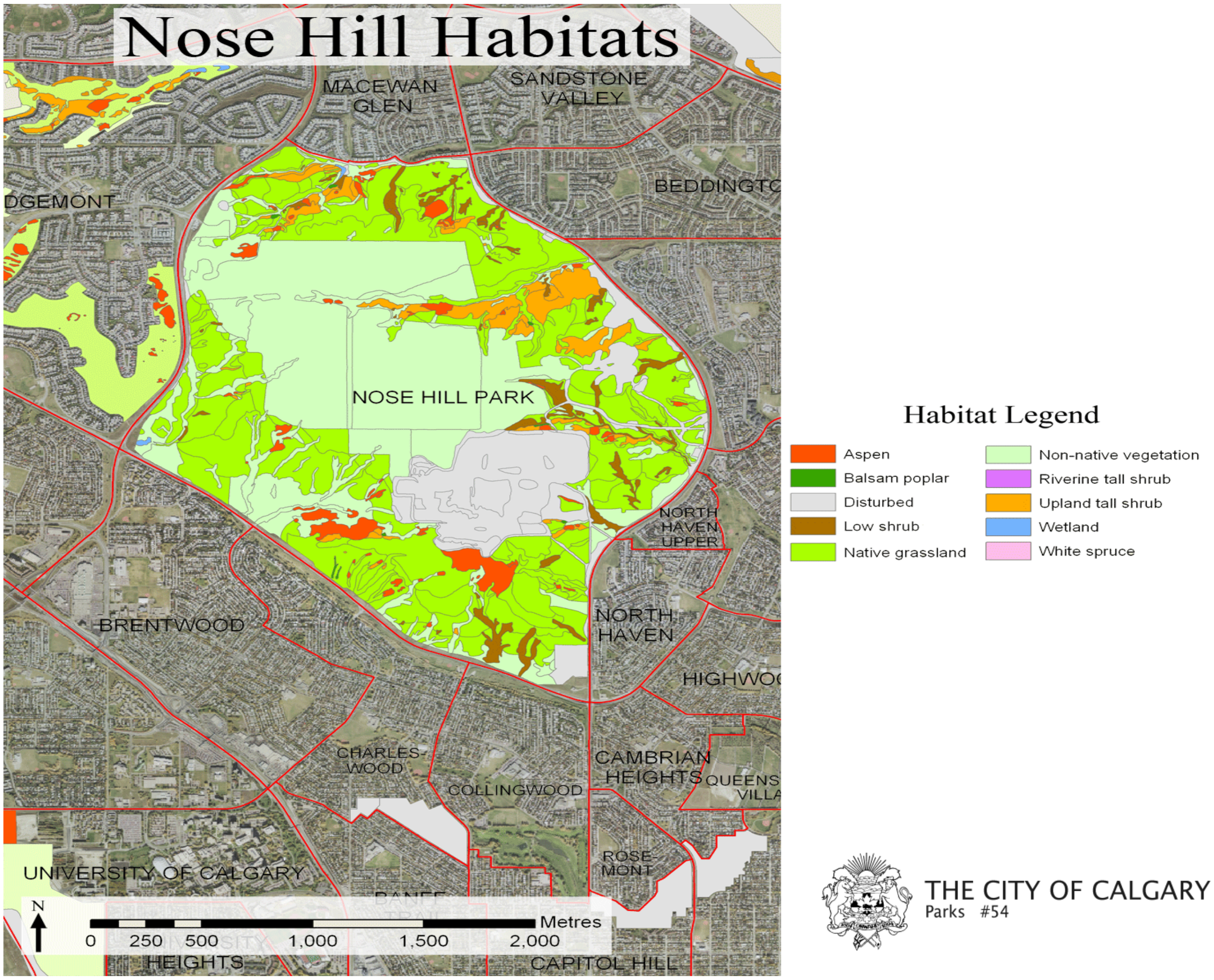


Map 2 Location of Nose Hill Natural Environment Park in the City of Calgary[3]

Nose Hill Park represents one of the most significant examples of native grassland ecosystem remaining in the North American Great Plains that is found within an urban area. There are distinctive vegetation zones in the park from the pre-dominant rough fescue community, groves of deciduous trees and shrubs found in the coulees and adjacent to water including the wildflowers found throughout the park. The aspen and the willows occupy the north-facing slopes of the coulees and provide a refuge for many of the wild animals living in the park. The rough fescue community is mainly composed of the Western wheatgrass, Rough fescue - Parry oatgrass, and Rough fescue - golden bean associations. A large portion of the park is considered non-native vegetation contributed by past agriculture and land clearing activities.

[3] City of Calgary. Natural Environment Park System, Arc GIS map.

The park is large enough to accommodate use by large mammals such as deer and coyotes which are often observed roaming the grasslands and coulees. Porcupines, Northern Pocket Gophers, Richardson's Ground Squirrels and several species of mice and voles are some of the common wildlife species that inhabit the park and are considered to be the keystone species for the Northern Harriers and Swainson's Hawks.



Map 3 Natural Habitats of Nose Hill Natural Environment Park[4]

Nose Hill is one of the two remaining examples of the high plains that had once covered Southern Alberta. Glacial actions and the erosive power of the ancient rivers have eroded the landscape creating the valleys and lowlands, leaving the hills untouched. Today, the hills are the two highest landscapes in the Calgary region. The most recent glaciers left glacial erratics consisting of rocks and debris carried deposited throughout

[4] City of Calgary. Nose Hill Natural Environment Park Habitats from Arc GIS data.

the park. One such erratic can be found on the east side of Nose Hill Park, assessed to have originated from Jasper National Park.

Figure 2 South facing slopes of Nose Hill Natural Environment Park. Photo courtesy of City of Calgary Parks

Nose Hill Park also contains numerous significant archaeological sites such as the stone circles or tipi rings. They were remnants of the historical aboriginal campsites. Stones were used to hold down the edges of tipis. The hill has long been known as a sacred place to the First Nation people used as a gathering site for ceremonies and burials.

European settlers began using the area in the late 1800's for farming and ranching. Large areas of the plateau have been ploughed and planted to agricultural crops.

Several restoration activities are currently being implemented to address a number of challenges the park is facing such as proliferation of undesignated trails, habitat degradation and invasive weed infestation. Through active habitat restoration and trail closure activities, the viability of the native grassland ecosystem is maintained ensuring habitat resiliency and health.

Nose Hill Park is one of the major destination points in Calgary, attracting people to enjoy various opportunities. Spectacular panoramic views of the city, countryside and the mountains are afforded by the elevation of the park in comparison to the surrounding lands. The park offers a diversity of terrains providing challenging active recreational opportunities such as trail running; mountain biking and hiking that is close to home. A number of cross-country trail running events have been held in the park over the years. Visitors are also attracted to the park's coulees and ravines, which provide a sense of solitude and isolation and allow users to experience an escape away from the city. Other visitors come to Nose Hill Park to enjoy the various cultural features, natural interest and ecological features found in the park. Dog walking is one of the more common activities in the Park. (Nose Hill Trail and Pathway Plan, 2007)

A number of user surveys were conducted to better understand how popular the park is and how people are using the parks throughout the city. Nose Hill Park is considered to be one of the more heavily used parks in the city. The study also included a survey of the various activities visitors were engaged in such as viewing the existing attractions, dog-walking, running, mountain biking and hiking. The attractions included cultural interest sites, including the tipi rings located in the southern portion of the park and the potential kill site located along Porcupine Valley. Viewing natural interest sites provided by the park are also common, which included the park's various glacial erratics (i.e. buffalo rubbing stone in the eastern portion of the park and erratics located near the nose of the park); as well as the exposed rock faces in the quarry. These attractions provide a glimpse into the geological history of Nose Hill. Vegetation communities of interest included those composed of native and non-native grassland species, as well as the early successional poplar communities located in the quarry. (Nose Hill Trail and Pathway Plan, 2007)

4. Economic Valuation

4.1 Ecosystem Services of Nose Hill Natural Environment Park

The term "Ecosystem Services" is defined as the benefits of nature to society, communities, and economies. Daily (1997) further elaborated that the benefits are socially valuable but are easily undervalued. Boyd and Banzhaf (2006) took a more economic approach in defining ecosystem services which considers accounting systems that allows the integration of performance accounting associated with weighting the services according to their relative value to society. According to their approach, functions and processes are not considered as services but simply interactions of ecosystem components resulting in the production of final services. It it important to distinguish the difference between services and benefits to ensure that appropriate terms are used to evaluate the value.

The Millennium Ecosystem Assessment uses similar approach in defining ecosystem goods and services. The services are categorized into four main groups:

- provisioning services such as food, fuels and fibres;
- regulating services that affect the climate, disease outbreaks, wastes and pollination;
- cultural services that provide aesthetic, recreational and spiritual value; and
- supporting services such as nutrient cycling, water purification and carbon sequestration. (Millennium Ecosystem Assessment, 2005)

The native grassland of Nose Hill Natural Environment Park provides a multitude of beneficial ecosystem services and the associated functions performed. The prairie landscape has been the quintessential symbol of the Prairie Provinces often associated with the Wild West culture of first nations' people, the cowboys and the farmers. The first nations' people in particular have a strong spiritual and emotional bond with the prairie landscape and the ecosystem.

Figure 3 Horseback riding in the prairies in Southern Alberta. Photo courtesy of Mike Quinn of the Pekisko Group.

The biophysical characteristics of native grasslands, in general are recognized as being tolerant to extreme weather variations such as drought and seasonal ambient temperature extremes. Several scientific studies on the functions of intact native grasslands reported that they are tolerant to extreme environmental conditions such as low-nutrient, saline and acidic soils and are often considered as indicators for changes in water tables. Healthy native grasslands are also capable of withstanding pest infestations.

Ecosystem benefits and services of native grasslands applying the definition derived by Boyd and Banzhaf (2006) are presented below.

Ecosystem Benefit	End-result products	Ecosystem Services
1. Presence of urban biodiversity		
	Open Space	Continuous tracks of native grassland
	Flora and fauna	Healthy habitats with weed species minimized
	Listed species protected	Healthy habitats with degradation minimized
2. Areas of respite		
	Aesthetic	Natural grassland landscapes
	Nature appreciation	Natural land cover over landscapes
3. Spiritual fulfillment		
	Psychological well-being	Natural grassland landscapes in urban areas
	Spiritual and emotional health	Cultural and heritage landscapes
4. Enjoyment		
	Nature in the city	Close to home
5. Environmental Integrity		
	Public health	Air quality, amelioration of climatic extremes
	Property quality	Amelioration of climatic extremes, sediment and

		erosion control
	Carbon sequestration	Air quality and storage of carbon
6. Recreation		
	Birding	Presence of a diversity of birds
	Hiking	Diversity of habitats, viewshed, close to home
	Biking	Diverse terrain
	Dog walking	Safe area for dog interactions

Table 1 Inventory of services and the associated benefits of native grassland in Nose Hill Natural Environment Park

4.2 Economic Valuation of Ecosystem Goods and Services

Conservation of environmentally significant areas[5] is one of the main goals of the City of Calgary Parks. Not only is Parks mandated under the Government of Alberta *Municipal Government Act* to acquire hazard lands such as ravines, coulees, escarpments and lands that are subject to flooding for public health and safety but also to provide public access for recreational purposes.[6] These lands are considered to be important sources for biodiversity in the city with the inherent ecosystem goods and services that are valued by society.

Calgary enjoyed an unprecedented economic growth during the early 21st century. The positive economic trends led to the increase of population. The influx of people brings

[5] Calgary Open Space Plan defines environmentally significant areas as areas meeting one or all of the following criteria:

- Quality of Biotic Community;
- Ecological Function;
- Distinctive and/or Unusual Land Form; and
- Uniqueness.

[6] **Ability to protect natural areas is based on the *Municipal Government Act***
A subdivision application may trigger a requirement for the surrender of land for:

- Road, public utilities
- Municipal Reserve (MR) — up to 10% taken for school sites and parks
- Environmental Reserve (ER) — Undevelopable lands

ER is defined as:

- a swamp, gully, ravine, coulee, or natural drainage course,
- land that is subject to flooding or is, in the opinion of the subdivision authority, unstable, or
- a strip of land, not less than 6 m in width, abutting the bed and shore of any lake, river, stream, or other body of water for the purpose of preventing pollution, or providing public access to and beside the bed and shore.

about various challenges not only to the city but also the region with respect to the environmental impacts due to urban development. Loss of biodiversity and important supporting habitats are evident in rural areas where land conversion activities run rampant to accommodate population growth. The values of ecosystems and the associated functions have been considerably undervalued during the cost-benefit analysis of urban development. The once expansive native grasslands throughout the city have been reduced to areas that are considered hazard lands and undevelopable. The remaining pristine tracks of native grasslands are found in remote areas of the city.

Conservation of these lands is constrained by the MGA legislation and political will of the land owner. The legislation narrowly outlines the provisions of natural area acquisitions while protecting the interests of the land owners. Economic values of these lands are high once converted to other land uses to be benefited by the land owner. Native grasslands are recognised as providers of the beneficial functions should be valued using the same economic principles. Understanding the economic values of the grasslands ecosystem goods and services would help provide a strong rationale for native grassland conservation.

For the most part, ecosystem goods and services are not traded in the market place. The valuation approach appropriate for ecosystem goods and services is a recent tool that considers society's willingness to pay for the goods and services. A number of economic valuation techniques have been developed in the recent years as tools to help conservation of biodiversity and open space. As Pearce and Moran (1994) pointed out that these techniques have strengths and weaknesses. They have established a set of criteria to help analysts and decision makers apply the techniques appropriately. The techniques applied should meet the following criteria:

- The technique applied should be technically acceptable with measures obtained for the valuation being consistent and accurate.
- The technique should be institutionally acceptable and aligns with the current decision making processes.
- The needs of the user should be considered when selecting the appropriate technique.
- The financial cost of the study should be measured against the value of the information gained.
- The use of multiple valuation techniques should be considered to help in comparing the results to arrive at the values that are statistically significant or with a greater confidence. (Pearce and Moran, 1994)

The Millennium Ecosystem Assessment reported that the Total Economic Value (TEV) as the most widely applied tool used to value ecosystem goods and services. TEV of ecosystem goods and services is comprised of use value which is derived from an actual use of a goods and services; and non-use value derived from future value of a resource. These two terms are divided further as illustrated in the diagram below.

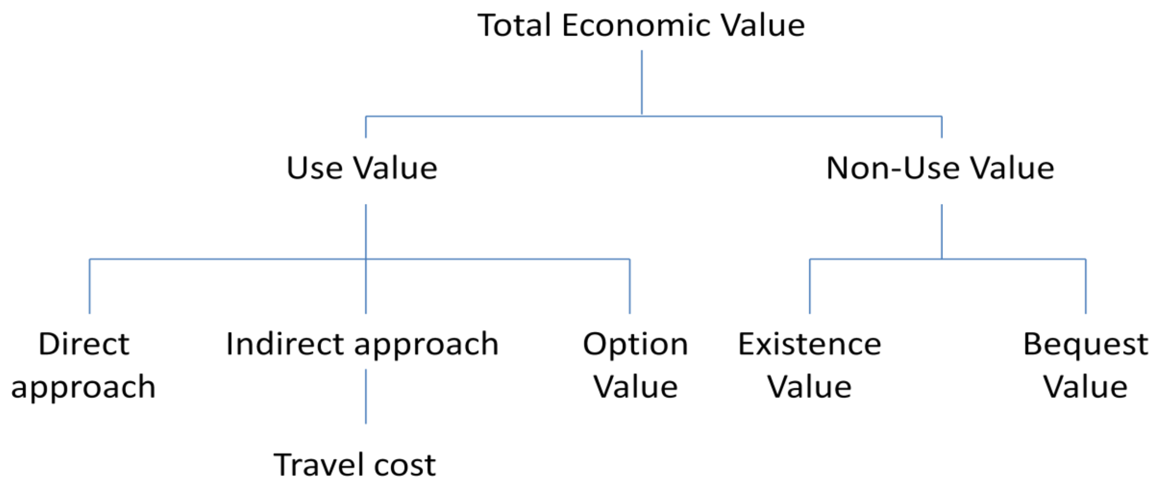


Figure 4 Total Economic Value Approach (Pagiola et al. 2004)

The direct approach uses values obtained from direct usage of the benefits of the ecosystem goods and services. An applicable example for the prairie region would include the prairie pothole wetlands as source water for agricultural purposes. This technique is reliant on surveys and experimental techniques to elicit information on public preference directly. Questionnaires are designed to ask participants of their preference for the ecosystem goods and services.

The indirect approach would rely on the benefits of the ecological function of the environment through observed market information. Carbon sequestration, biodiversity and amelioration of weather extremes functions are some of the indirect uses provided by native grasslands in the prairie region. Preference for the ecosystem goods and services are revealed indirectly when the associated marketed goods and services are purchased. (Pearce and Moran, 1994)

The option value implies that the ecosystem benefits are available for use in the future. Non-use values include the existence and bequest values. The existence value applies the value of benefits resulting from the knowledge that the goods and services exist in perpetuity. Bequest value is the value of the benefit of the resource retained for future generations inheriting the goods and services of the present generation.

4.3 Ecosystem Benefit Transfer Approach

The ecosystem benefit transfer approach is commonly used when analysis is not easily performed or the data available is insufficient for analysis. The approach relies on values of the ecosystem benefits of a similar resource from another location be adapted to the local situation to address the existing valuation needs.

The benefit transfer approach is gaining popularity amongst decision makers. It is attributed to the ease of use and practicality when data is unavailable at the target location or valuation analysis cannot be performed due to time and budgetary constraints.

5. Economic Valuation Approach for Nose Hill Natural Environment Park

This study focuses on evaluating the recreational value of Nose Hill Park using the existing data and information on public use and park management and improvements activities implemented in the recent years. The recreational value is one of the fundamental services of an urban park such as Nose Hill Park. The value is dependent on the rate of visitors enjoying the park and the market goods expended during the visits.

Recreational benefit is commonly considered as a product of utilizing the ecosystem services and conventional goods and services. It is important to distinguish the difference between services and benefits to ensure that appropriate terms are used when evaluating the target value. The recreation activity is a result of the benefit acquired from the expenditure of the ecosystem services and market goods. Nose Hill Park provides recreational benefits for visitors who utilize market-based products such as the vehicles, bicycles, running shoes or hiking boots and the various inputs of ecosystem services from biophysical characteristics, environmental quality to sociological and cultural elements all of which are inherent values embodied in the final product.

As previously mentioned, a number of economic valuation techniques exist for assessing values of ecosystem goods and services. The travel cost approach is thought to be the most appropriate technique for evaluating the recreational value of Nose Hill Park. The approach relies on the simple travel cost model to estimate consumers' recreation demand functions. The visitors' travel costs act as a proxy for the price they are willing to pay to recreate at the park measuring the use value associated with the park. (OECD, 2002) The approach will use information on the number of people visiting the park to estimate the WTP for the park.

Economic demand theory implies that less of a good or service is demanded as the price for the product is increased. Essentially, as the travel cost increase, the quantity demanded for the recreation in the park would decrease.

The City of Calgary recognizes this economic principle as an important factor in ensuring that parkland is available for public use in neighbourhoods. The City conducted a study that identified the per capita threshold for open space in established communities. (The City of Calgary, 2006)[7] The established threshold for neighbourhood open space is 2 hectares per 1000 residents. As more people move into the neighbourhoods, the demand for open space increases.

Another important element of the travel cost approach is its applicability for determining the value of environmental quality attributes of a park by observing how visitation rates to a site change as the environmental quality changes. The size of the park and the existing biophysical characteristics are important considerations for increased consumer use. The larger the park and the more diverse the characteristics are the more attractive the park is to the consumers. As a result, the demand for the park's services and the park's ability to provide the recreation activities are major factors for attracting the visitors. As the quality of the park improves, one would expect the number of visits would increase thereby increasing the value of the park.

5.1 Limitations of Economic Valuation of Nose Hill Natural Environment Park

The analysis is constrained by the availability and reliability of the data available. Although Nose Hill Park has been well studied by the Parks department and local naturalist groups, the data available may not be relevant for use in the valuation analysis. The user studies conducted by the Parks department were to fulfill the need to understand the public use preferences, demographics, and how well the park is being utilized. An important consideration is that the studies were conducted at least 13 years ago making the data outdated and not reflective of the current conditions.

The studies do not provide any information from where the visitors originated from. The current analysis will depend on an assumed travel distance of up to 5 km from the park which will inadvertently miss the visitors travelling further away to recreate in Nose Hill Park. As a result, the assumption cannot consider any visitations made by those who live either farther away or within the 5 km radius of the park.

The use studies did not specifically target the park's attributes and a reference to the place of origin. These variables were eliminated from the analysis.

---

[7] Open Space Strategy for Established Communities, 2006 examined the adequacy and role of local and regional open space in established in Calgary within the intent of identifying the deficiencies in quantity and function; determine the standards for quality and quantity; identify key priority areas for park improvements and acquisition; determine urban design principles for parks; examine the role of school yards in open space system; address the Triple Bottom Line, including the social, environmental, and economics; and ensure effective public engagement in the review process.

5.2 Analysis

A simple travel cost model is used to estimate the recreation value. Data such as number of visitation per day over time whether it be season or month was applied to derive the recreation demand function identified as WTP value. Evaluating the consumer WTP to travel to the park would require an understanding of the recreational value. The quality of the park through park management and infrastructure improvements is also another important factor for consumer preference.

The method applied for the travel cost analysis includes the following selection of variables:

- Visitor numbers
- Destination location – distance
- Visitation rates – dependent variable
- Travel cost estimate – independent variable
- Quality of the park – dependent variable

There are two sets of park visitation data available for the analysis, namely the 1997 Nose Hill Park User Study and the 2008 Off-leash Dog Park Use Study. Both reports were conducted to provide visitation data used to support different decision-making processes for park management purposes and the formalization of off-leash dog management policy, respectively.

The 1997 Nose Hill Park User Study reported an average of 5,426 people visited the park every week during the busy times between 7 to 9 pm over the months of June and July and August.

The more resent use study conducted in 2008 which had reported a total of 3,237 visitors over a four-day period in October. The study also provided the visitation rates per day with Wednesday having 47.7 visitors per hour and a total visit of 525, Thursday having 58.8 visitors per hour totalling 647 visits, 71.1 visitors per hour or 789 people visited on Saturday and 116.0 visits per hour on Sunday bringing 1276 people to the park.

The 2008 use study provided a more comprehensive and accurate data on the number of visits during the study period. The data was collected over a longer period of time per day which increases the reliability in the data for the analysis. The earlier study on the other hand was undertaken over a shorter period of time. Furthermore, the result failed to fully represent the actual condition of usage throughout a full day during the study period. The amount of data acquired over the two hour period per day over the three months of summer is insufficient for use in this analysis.

Three assumptions were made in order to fulfill the requirements of the demand function. First of all, a 5 km distance from the park was used for the analysis to estimate the recreation value of the park. The assumed 5 km radius would include the communities of Banff Trail, Beddington, Brentwood, Capitol Hill, Dalhousie, Edgemont, Hamptons, Hidden Valley, Highwood, Huntington Hills, MacEwan, North Haven, Sandstone, Triwood.

Second, the visitors travel to the park using several modes of transportation from vehicles, public transportation system, bicycles and on foot. The cost of travel is dependent on the mode of transportation. If a person travels to the park driving a vehicle, the analysis would need to consider the market cost of the vehicle; the cost of fuel; maintenance cost of the vehicle; vehicle insurance and registration cost. If the mode of transportation is public transit, then transit fees would need to be considered. On the other hand, cycling and walking to the park would rely on the market cost of the bicycles and shoes. Another factor that would need consideration is the cost of time spent on travelling. The use of vehicle cost rate has been determined by the City of Calgary as part of the organization's fleet management requirements. The cost rate is established at $0.50 per kilometre of travel per vehicle. The use of public transit, bicycles and foot will not be considered in the analysis. A detailed use study is required which is outside the project scope and budget.

Third, the number of days the survey was conducted was limited to Wednesday, Thursday, Saturday and Sunday. The visitation numbers for Wednesday is applied to the other week days including Monday and Tuesday. Thursday's visitation numbers is used to extrapolate the number of visitors on Fridays.

5.2.1 Willingness-to-Pay Value

The recreational value is then applied to evaluate the WTP to travel to Nose Hill Park. This analysis allows the information and data of the quality of the park to influence the consumer preference when making the decision whether to visit the park or not. It assumes that the quality of the park is determined by the activity inputs performed by the Parks department. If the park is intensively managed with inflows of capital and operation budget expenditures, the consumer WTP would also increase would be reflected in the increase in the number of visitors to the park. The consumer willingness to pay to travel is represented in the following simple utility demand function:

$$WTP = f(X, Y)$$

Where X is the recreation value calculated by multiplying the total number of visitors with the distance travelled and the travel cost; and Y is the quality of park contributed by the amount of infrastructure investment inputs. The function for estimation and the coefficients *a* and *b*:

$$WTP = a + bX$$

Day of week	# of days per month	# of visitors/ day	Total visits	Travel radius (km)	Total Travel distance (km)	Travel cost ($/km)	Recreation value ($)
Monday, Tuesday, & Wednesday	14	525	7350	5	36,750	.60	22,050
Thursday & Friday	8	647	5176	5	25,880	.60	15,528
Saturday	4	789	3156	5	15,780	.60	9,468
Sunday	4	1276	5104	5	25,520	.60	15,312
Total			**20,786**				**62,358**

Table 2 Calculation performed to assess the recreational value of Nose Hill Park

Based on the calculation performed, the total number of visitors per month is 20,786 which contribute to a considerable recreational value of $51,965 per month and $623,580 per year.

The total visit and recreation value variables in the demand function are regressed to perform the estimation regression. The result is presented in the following table.

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	1
Standard Error	4.47E-13
Observations	4

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	55063618.75	55063618.8	2.75E+32	3.64E-33

Residual	2	4.00382E-25	2.0019E-25
Total	3	55063618.75	

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.8E-12	8.14643E-13	-2.2328674	0.155192	-5.3E-12	1.69E-12
X Variable 1	2.5	1.50741E-16	1.6585E+16	3.64E-33	2.5	2.5

Table 3 Estimation regression for the total visits and recreation value

The slope coefficients $\hat{a}$ & $\hat{b}$ are estimated for statistical significance. The standard error is considerably small at 4.47-13 signifying that the coefficient b is accurate and the more probable it is that the true value of b is not equal to 0. The t-ratio is The R^2 and the adjusted R^2 are both 1 which indicates that the Y and X are highly correlated. Furthermore, the F-statistic is greater than the critical F-value with 2 degrees of freedom and the 0.05 level of significance. The regression equation is found to be statistically significant.

The WTP is then calculated to obtain the following value of $129,912.30.

$$WTP = -1.8^{-12} + 2.5(51{,}965)$$
$$= -1.8^{-12} + 129{,}912.5$$
$$= \$129{,}912.30$$

5.2.2 Future Recreational Value of Nose Hill Park

The management of parks and open space is centered on the maintenance of the functions and values. The question commonly asked is “With the inflow of operation and capital dollars now, what would be the value of the park in the future, say 10 years from now?” One would think that the value of the park would increase just as any investment annuity would. Using the present value (PV) of the recreational value of Nose Hill Park calculated earlier, the future value stream can be estimated using the Present Value Calculation. The calculation assumes that the current (2010) savings bond rate of 1.7% rate of return.

$$PV = \$X \div (1.07)^t$$
$$= \frac{\$623{,}580}{1.07^{10}}$$
$$= \$5{,}690{,}309.41$$

If the recreational value of Nose Hill Park is $623,580 per year, and the value is invested in Canada Savings Bond with a rate of return of 1.7%, in ten years the total value of the park would be worth $5,690,309.41 today.

5.2.3 Relationship of Recreational Value to the Quality of Nose Hill Park

The Parks department has continuously made infrastructure improvements to Nose Hill Park. The Nose Hill Trail and Pathway Plan (the Plan) was developed to guide the improvement activities while addressing the proliferation of informal trails and unauthorized uses which had contributed to habitat degradation as a result of vegetation loss, the spread of invasive plants, habitat fragmentation and loss of soil and soil fertility due to compaction. The intent of the Plan is to perpetuate the natural character of the Nose Hill landscape while providing compatible, quality recreation opportunities. (NHTPP, 2005) The budget allocated for plan implementation is presented in the following table.

Project Details	**Detail Sub-total**	**Total cost**
Construction costs (Trails & Pathways, Signage, Parking Lots and other activities that include habitat restoration and construction damage repairs		$5,845,198.00
Contingency (10%)		$584,519.80
Design Costs		
Trails (10%)	$298,650.00	
Pathways	$10,000.00	
Signage	$53,650.00	
Parking Lot	$39,822.00	
Total Project Costs		**$6,801,839.80**

Table 4 Total budget allocated for the implementation of Nose Hill Trail and Pathway Plan

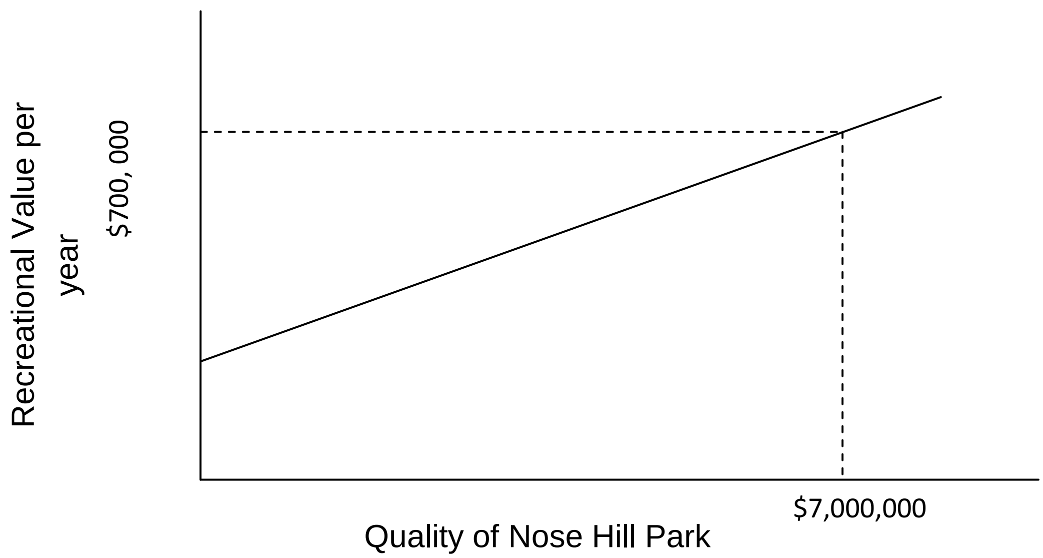


Figure 5 The estimated relationship between the Recreational Value and the Quality contributed by infrastructure improvements in Nose Hill Park

The illustration above is used to demonstrate the increase in recreational value as the expenditure in infrastructure increases. Without any park infrastructure improvements, people would still visit the park and benefit from the recreational value the park offers. As more people use the park, the natural landscapes may become compromised due to vegetation trampling, soil erosion and habitat loss. Park management is an important activity that ensures landscapes and habitats are maintained in good health while accommodating recreational opportunities.

As pathways become formalized and paved for ease of use, the more attractive the park becomes to more visitors such as those with mobility issues. Habitat restoration also plays an important role in improving the quality of the park. The more native habitats are found in the park the more attractive the habitat to indigenous wildlife species which ultimately will contribute to the beneficial biodiversity goods and services.

Over the years, loss of wildlife species in Nose Hill Park has been execrated by the increase in park use by people. Establishment of habitat management zones in parks help to minimize encroachment of public use in critical wildlife habitats. Furthermore, these zones help to prioritize management activities to the areas with compromised habitat quality by implementing activities that result in quality improvements. Such activities include intensive habitat restoration, trail closure and infrastructure development.

6. Cost – Benefit Outcomes of Native Grassland Conservation

Land conversion is one of the major contributors to the loss of native grassland in Alberta. As mentioned, urban development in Calgary has increased with the increase in population. More land is needed to build new communities as well as keep up with the economic demand for retail, employment and services. The City has taken the leadership role in providing the strategic framework to manage growth in a sustainable manner that ensures the City's ecological footprint[8] is managed. The City of Calgary Municipal Development Plan (The MDP) was prepared to provide strategic direction to support corporate decisions around managing growth, change, prioritizing corporate initiatives and public investments. (The City of Calgary, 2009) The MDP recognizes that the environment and economy are connected. The land use and mobility decisions made today affect the environment and economic growth in the future. Furthermore, it also acknowledges that urban growth has implicit impacts on the natural environment.

Residential development in Calgary occurs in the suburban fringe where land use conflicts are prevalent. Subdivision plans are developed in accordance to the MDP and the approved land use policies. Economic analysis would be done to ensure that the cost of development is minimized and the bottom line is maximized. The cost of stripping and grading; infrastructure installation; road building and stormwater management facilities constructed to name a few, are accounted for in the bottom line analysis. However, loss of biodiversity, contiguous open space and local recreational area are typically ignored.

The recreational value of an open space exists in perpetuity available for everyone to use now and in the future. Based on the recreational value of Nose Hill Park estimated in the preceding section, the recreational value of $623,580 per year would be lost if a natural environment of similar characteristic and size is converted to other land use types. If a development project allocates an ESA land as Environmental Reserve, this allocation of land not only continues to provide biodiversity goods and services but also offers recreational opportunities for the residents of the future development project.

Currently, the residential development costs are as high as $40,000 per acre, industrial development is approximately $400,000 per acre and commercial development can be more than $800,000 per acre. (Nieuwenhuis, pers. com., 2010) Alternatively, the opportunity cost of economic benefit from developing a natural environment may be forgone if the land is maintained as open space or park but the societal benefit is maintained in perpetuity.

[8] Calgary Ecological Footprint was initiated in 2008 to provide communities and organizations with information on Ecological Footprint reduction.

7. Summary

Nose Hill Park is one of the more popular urban parks in Calgary. It provides a wide range of benefits and function to Calgarians in general, one of them being recreation. Parks' fundamental tenet of park acquisition and management is the promotion of open space and biodiversity in the urban context for society and offers the intrinsic benefit of recreation opportunities for Calgarians.

The number of visitors recreating in the Nose Hill Park is considerable with a monthly average of more than 20,000 visitors. As mentioned, the previous studies used in this exercise did not include where they came from. Assuming that the majority of the visitors live in close proximity to the park, they may have travelled at an average distance of 5 km to the park. The analysis also assumed that the vehicular mode of transportation is the likely chosen mode during park visits. The cost of vehicular use during these travels is assumed to be $0.50 per km. With that in mind, the recreational value of the park was then calculated to $62,358 per month and the willingness to pay to travel to the park is valued as $129,912.30.

Understanding the economic value of recreation benefit in natural areas alone can provide a strong rationale for open space conservation. Native grasslands offer a multitude of other functions and benefits to society. Their economic values should be further investigated to ensure that they are considered as part of the decision making process for open space acquisition.

8. Recommendations

There are a number of data gaps encountered during this analysis. Accurate and relevant data and information such as where the visitors originated from, how they arrived at the park and the length of time spent in the park. A park use study should be conducted if more economic valuation projects are proposed. The project should be better designed to include a socio-economic survey questionnaire and delivered over an extended period to time that ensures accuracy and representative of the current situations.

The economic valuation analysis was only conducted on one benefit – the recreational value. Analysis of other benefits and functions should be conducted applying the tools described above. Biodiversity conservation typically depends on Parks ability to acquire environmentally significant areas and landscapes using the legislated tools but also other tools such as Conservation Easement, Conservation Design, Conservation

Transfer of Credits to name a few. These tools would require defensible rationale to support the decisions to expend capital budget for acquiring open space and landscapes. Economic valuation may be the tools needed to justify the need to purchase land for conservation purposes.

Bibliography

Achuff, P.L. 1994. *Natural Regions, Subregions and Natural History Themes of Alberta Classification for Protected Areas Management*. Prepared for Parks Service, Alberta Environmental Protection. Updated and Revised December 1994.

Ajtay, G.L., P.Ketner, and P. Duvigneaud. 1979. *Terrestrial primary production and phytomass*. In The Global Carbon cycle, ed. B. Bolin, E. Degens, S. Kempe, and P.Ketner, 129-82. SCOPE Volume. 13. Wiley. Chichester.

Albert Prairie Conservation Forum. Website. Downloaded April, 2010.

Bailey, R.G. 1998. *Ecoregions*. Springer. New York.

The City of Calgary, 2008. *Calgary Ecological Footprint project – Reducing the Ecological Footprint ; A Calgary Approach*. Calgary.

The City of Calgary, 2009. *The Municipal Development Plan*. Calgary.

The City of Calgary Parks. 2005. *Nose Hill Trail and Pathway Plan for Nose Hill Park*. O2 Planning and Design. Calgary.

The City of Calgary Parks. 2008. *Off-Leash Areas Study.* Business & Market Research, Recreation Department, The City of Calgary. Calgary.

Coupland, R.T. 1950. *Ecology of mixed prairie in Canada*. Ecological Monographs 20:271-351.

Daily, Gretchen. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, DC: Island Press

Ducks Unlimited Canada and Nature Conservancy Canada. *The Value of Natural Capital in Settled Areas of Canada*.

Government of Alberta. *Municipal Government Act,* Sect. 664(1)

Kennedy, M. And J. Wilson. 2009. *Natural Credit: Estimating the Value of Natural Capital in the Credit River Watershed.* Pembina Institute and Credit Valley Conservation.

Kumar, P. 2005. *Market for Ecosystem Services.* International Institute of Sustainable Development. Winnipeg.

Luaenroth, W.K.; I.C. Burke; and M.P. Gutmann. 1999. *The Structure and Function of Ecosystems in the Central North American Grassland Region*. Great Plains

Research: A Journal of Natural and social Science. University of Nebraska – Lincoln.

Lange, G-M. 2003. *Policy Applications of Environmental Accounting*. The World Bank Environment Department. International Bank for Reconstruction. Washington.

Nieuwnehuis, G. 2010. Personal communication of cost of urban development.

Pagiola, S.; K. von Ritter; J. Bishop. 2004. *Assessing the Economic Value of Ecosystem Conservation.* Environment Department Paper No. 101. The World Bank Environment Department. The International Bank for Reconstruction. Washington.

Pearce, D. and D. Moran. 1994. *The Economic Value of Biodiversity*. IUCN – The World Conservation Union. Earthscan Publications Limited. London.

Voora, V. A.; and H. D.Venema. 2008. *The Natural Capital Approach: A Concept Paper*. International Institute of Sustainable Development. Environment Canada – Policy Development Division. Winnipeg.

Whittaker, R.H., and G.E. Likens. 1975. *The Biopshere and man*. In Primary Productivity of the Biosphere, Ecological Studies, Vol. 14, ed. H. Lieth and R.H. Whittaker, 305-28. New York:Springer-Verlag.

Wilson, S.J. 2009. The Value of BC's Grasslands: *Exploring Economic Ecosystem Values and Incentives for Conservation.* Grasslands Conservation Council of British Columbia.

Multifunctionality of paddy fields in Taiwan- A conjunction evaluation method of Contingent Valuation Method and Analytic Network Procedures

Ya-Wen Chiueh

Associate professor,
Department of Environmental and Cultural Resources, National Hsinchu University of Education
No.521, Nanda Rd., Hsinchu City 300, Taiwan
Tell: +886-920-478-753 FAX: +886-3-5647596 Mail:yawen@mail.nhcue.edu.tw
yawen.chiueh@gmail.com

Multifunctionality of paddy fields in Taiwan- A conjunction evaluation method of Contingent Valuation Method and Analytic Network Procedures

ABSTRACT

This study attempted to use the benefit and value assessment method, in conjunction with Contingent Valuation Method (CVM) and Analytic Network Procedures (ANP), and through the use of survey questionnaires, to assess the preference structure and relative weight scales of the people for the multifunctionality function and production output benefits that are derived from paddy fields. The monetization of the value of the multifunctionality of paddy fields are as below:1) benefits production values are 22.85 N.T from 1kg of rice, 2) benefits from food safety and reliance are 34.83 N.T from 1kg of rice, 3) benefits from cultural heritage and community development are13.67 N.T from 1kg of rice, 4) benefits from recreation and landscape are 12.59 N.T from 1kg of rice, and 5) benefits from environmental conservation are 24.73N.T from 1kg of rice. The ratio of nonmarket/rice production is 3.756. These benefits from the production values are the source of GDP of rice production. These benefits from all of the five categories are the source of Green GDP of rice production. This study calculated the GGDP of rice production which included market price of rice production and non-market value of multifunctionality of paddy fields that generated 158 billion NTD in 2008. The ratio of rice production output over real production output ratio, as designed by our study, obtained a result close to 1, showing that the benefit assessment for market goods and non-market goods, in conjunction with ANP and CVM, has been a reliable assessment method, therefore it shall be further promoted in the future.

Keyword: multifunctionality, Contingent Valuation Method, Analytic Network Process, conjunction evaluation method, Green GDP

1. Introduction

The multifunctionality of paddy field includes objective and subjective components. The objective components are focused on the factual aspects, such as the living conditions, ecological quality and economic development. The subjective components are focused on both the use and nonuse value of multifunctionality of paddy field. However, before the actual assessment, researchers need first to understand the peoples' values and preferences in consideration of the production of food, environment improvement, and cultural impact from paddy fields. This study used the benefit and value assessment method, in conjunction with Contingent Valuation Method (CVM) and Analytic Network Procedures (ANP), and through the use of survey questionnaires, to assess the preference structure and relative weight scales of the people for the environmental and production output benefits that are derived from paddy fields.

The monetization of the value of the multifunctionality of paddy fields included five categories of benefits, including 1) benefits from production values, 2) benefits from food safety and reliance, 3) benefits from cultural heritage and community development, 4) benefits from recreation and landscape, and 5) benefits from environmental conservation. These benefits from 1) the production values are the source of GDP of rice production. These benefits from all of the five categories are the source of Green GDP of rice production. This study calculated the GGDP of rice production which included market price of rice production and non-market value of multifunctionality of paddy fields.

This study use the conjunction evaluation method with ANP and CVM, calculated the Green GDP of rice production which included market price of rice production and non-market value of multifunctionality of paddy fields that generated 158 billion NTD in 2008. The ratio of rice production output over real production output ratio, as designed by our study, obtained a result close to 1, showing that the benefit assessment for market goods and non-market goods, in conjunction with ANP and CVM, has been a reliable assessment method, therefore it shall be further promoted in the future.

2. Research Method

According to a special task force of the International Water Association Asia Pacific Regional Group that worked on "the Multiple Roles and Diversity of Irrigation Water," the multifunctionality of paddy fields includes "food", "environment", and "culture" functions, in which the functions of food are safe and stable food supply; the functions of environment include flood prevention, stable river flow, groundwater recharge, prevention of soil erosion and landslides, maintenance of biological diversity, and landscape maintenance; and the functions of culture include cultural values, traditions, practical experience and education in the field, shown in Figure 1.

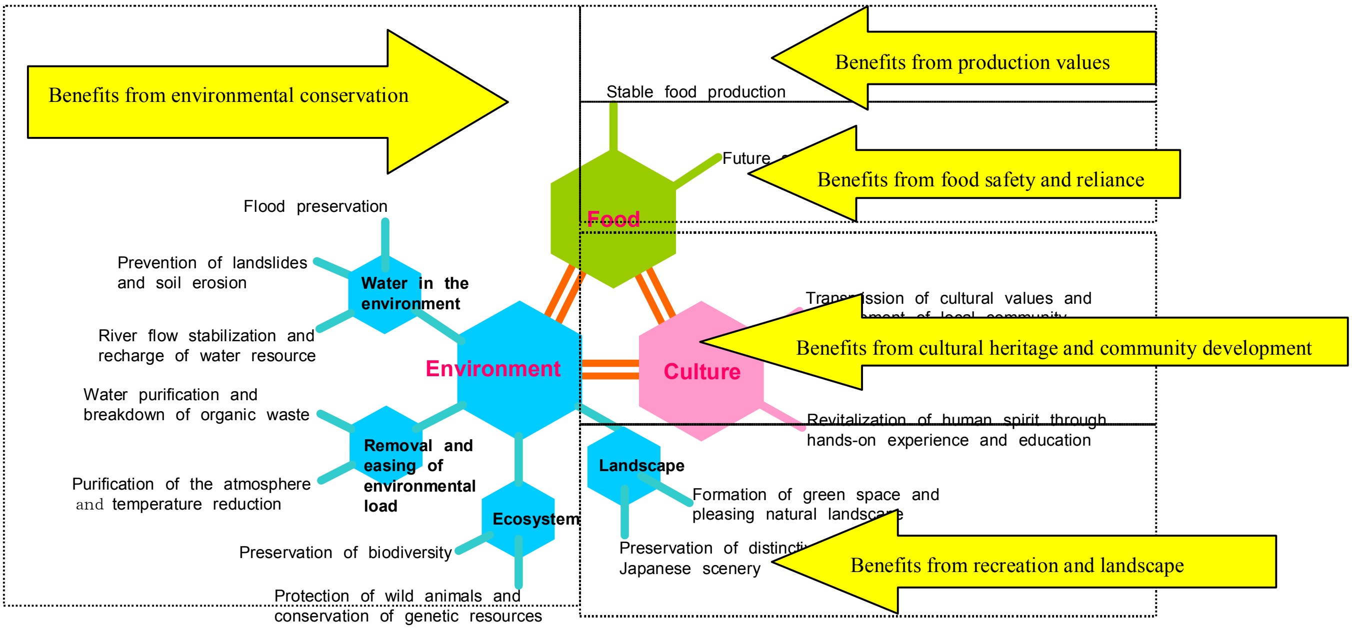


Figure 1：The benefits of multi-functionality of paddy

Source: This study revised from ASRWG (2006)

During the WTO technical meeting on Multilateral Environmental Agreements, the possible conflict between WTO rules and various international protocols and conventions on environmental protection was fiercely debated. Kim, et al. (2006) indicated that the Asian monsoon regions should evaluate the characteristics of multi-functionality of paddy farming correctly and transmit them to the people of Western countries. The benefit assessment has its objective and subjective components. The objective component is focused on the veritable aspects of the benefits, which can be defined as the actual effects of "food", "environment", and "culture" functions derived from rice production. The subjective component is focused on the human value aspects, for which we must first understand the value system and personal preferences of the people concerning the benefits derived from the multifunctionality (i.e. the food, environment, and culture functions) of paddy fields before any meaningful benefit assessment to be made.

The multifunctionality of rice production basing on the food, environment, and culture factors can actually enhance the human well-being. According to the human value aspects, this article has categorized the multifunctional benefits of rice production into "benefits from production values" that represent the benefits of food production and income from paddy fields that can be estimated from its market value; "benefits from food safety and reliance" that represent the benefits of food safety and reliance that are established in the people’s mind over time; "benefits from cultural heritage and community development" that represent the continuation of cultural values and community development, and the benefits derived from actual experience and education in the field for enhancing the human spirits; "benefits from recreation and landscape" that include the benefits from the green space and natural landscape, and the benefits derived from landscape preservation; and "benefits from environmental conservation" that include the benefits derived from flood water regulation, landslide prevention and soil loss prevention, river flow stability, replenishment of groundwater, river flow controls, water purification and decomposition of organic pollutants, air purification, regulation of temperature, maintenance of biological diversity, protection of wildlife, genetics preservation, and other functions, indicated in Figure 1.

The benefits from food safety and reliance, the benefits from cultural heritage and community development, the benefits from recreation and landscape, and the benefits from environmental conservation are considered as non-market good. These benefits from "the production values" are considered as market good, which are the source of GDP of rice production. These benefits from both market and nonmarket good of the multifunctionality paddy field are the source of Green GDP of rice production.

For assessment of the benefits derived from the food, environmental, and cultural effects of rice production, most of the researches use the replacement method, or the Contingent Valuation Method (CVM) to assess the benefits derived from non-market goods concerning the multifunctionality of paddy fields. Chang & Ying(2005) estimated the willingness to pay（WTP）of the water preservation and land protection function for rice fields in Taiwan by the assumption that the water preservation and land protection function would completely disappear without government payment. Aizaki, et al. (2006) used a realistic assumption to measure the multifunctionality of agriculture and rural areas in Japan.。Chiueh & Chen(2008) use Contingent Valuation Method（CVM） to evaluates the value of multifunctionality of paddy fields from the purposefully selected pool of samples in Taiwan.

Studies show that the CVM enables the assessment of benefits by monetization of the multifunctionality of paddy fields. However, using the CVM for the overall assessment of the agricultural multifunctionality cannot identify the personal preferences and value system. The multifunctionality of rice production can be viewed as complex economic goods with complementary effect, since the food, environment, and culture functions would happen simultaneously and tend to complement each other. Generally speaking, it is not easy to distinguish the preference structure of consumers among the complexity of agricultural multifunctionality existing in the complex economic goods. In our value assessment process, in order to evaluate the complexity of various properties and the preference structure derived from the agricultural multifunctionality, Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are used in conjunction as these methods can provide good Analytic results. This research attempted to develop a conjunction evaluation method from the CVM and ANP in order to provide overall evaluation of the agricultural multifunctionality, and to understand the preference structure of the people derived from the agricultural multifunctionality, shown in Figure2.

2.1. Analytic Network Process

This study attempted to use the benefit and value assessment method, in conjunction with Contingent Valuation Method (CVM) and Analytic Network Procedures (ANP), and through the use of survey questionnaires, to assess the preference structure and relative weight scales of the people's preference for the environmental and production output benefits that are derived from paddy fields. Chiueh Ya-Wen(2002) had used Analytic Hierarchy Process (AHP) to assess the Green GDP from rice production, but the study was constrained by the limitations of the AHP method, which assumed that the decision-making criteria were mutually independent, and that there was no interaction of events. It is evident that their research is based on the assumption that the three functions of paddy fields are separate and independent events. However, the validity of this assumption has often been questioned by other researchers, as it does not conform to the human decision-making process (Saaty, 2008), and also does not agree with the fact that the three functions of paddy fields are dependent on each other and often occur simultaneously. Therefore, this research uses the Analytic Network Procedures (ANP) to modify the valuation results. ANP is characterized by its close-to-human thinking process. Since the decision-making criteria do not have to be independent, the dependency factor and feedback effect can be included in the decision-making criteria, such as the cluster interaction and feedback effect. Supermatrix is then able to calculate the degree of dependency for each other, so that the original regularized hierarchical structure will become a complex network structure similar to "Amoeba", enabling more appropriately description of the characteristics of the problem by the researchers (Saaty, 2008).

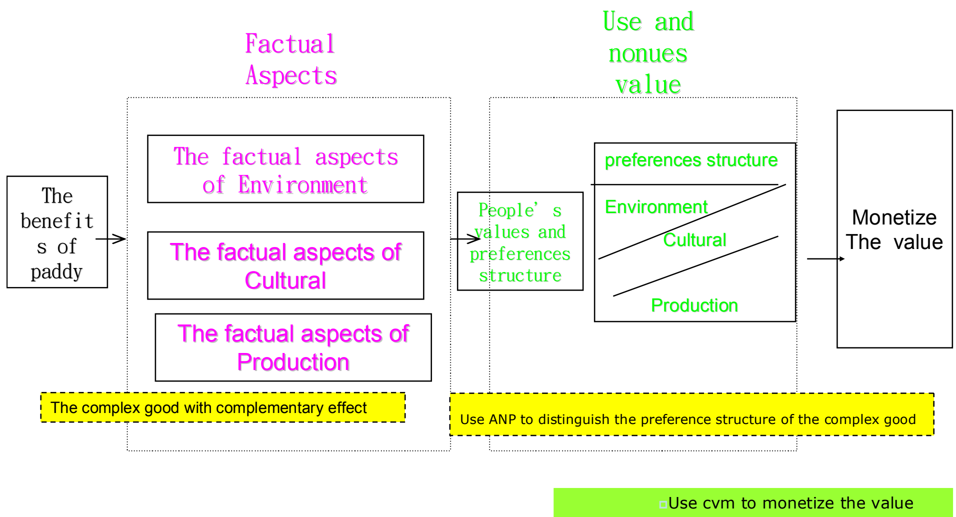


Figure 2：A conjunction evaluation method of Contingent Valuation Method and Analytic Network Procedures
Source: This study.

Since the food, environment, and culture functions of rice production are interdependent and mutually affect each other, it shall be suitable to apply the Analytic Network Procedures (ANP) to evaluate the preference structure. This study plans to develop the benefit and value assessment method in conjunction with CVM and ANP in order to assess the market and non-market benefits of economic goods and the preferences structure, so as to provide an overall assessment of the benefits and preference structure of the people derived from the multifunctionality of rice production.

For its close-to-human thinking process, and the fact that the decision-making criteria need not be independent, ANP enables the original regularized hierarchical structure to be changed to a complex network structure similar to “amoeba” (Saaty, 2008). The food, environment, and culture functions of rice production are interdependent and tend to influence each other in the process of producing their benefits with human values, shown in Figure 3.

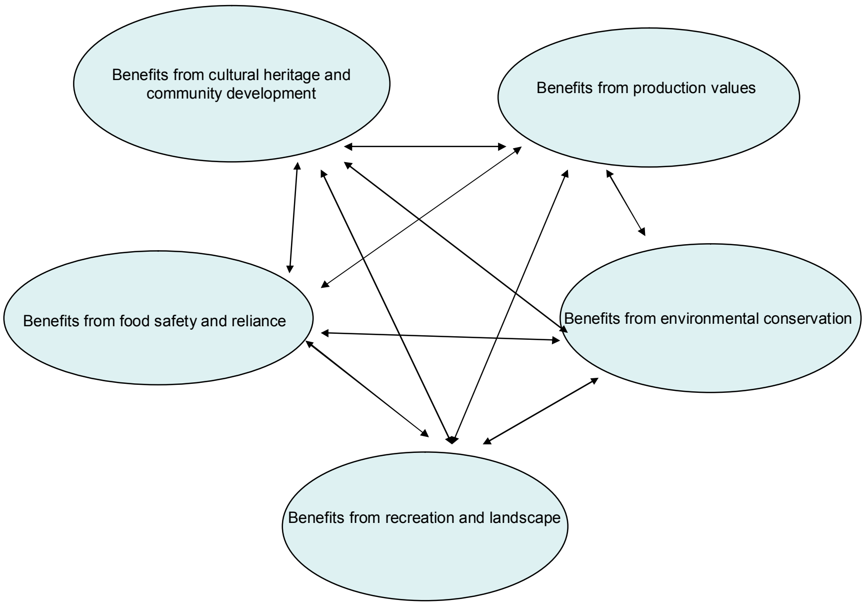


Figure 3：Complex network preference structure of multifunctionality of paddy fields

Source: This study.

2.2. Contingent Valuation Method

The household production model was employed when Freeman (1993) established his theory on benefit evaluation for non-market goods. The same model is used here.

The price of general goods PX, the price of domestic rice products P, and the income of M under the given level of agriculture protection Q are all independent variables that have an influence on the demand of the household. By Freeman (1993) the indirect utility function U^0 of the household shown below.

$$U^0 = V(P_X, P, Q, M) \tag{1}$$

In light of the fact that utility function is immeasurable while expenditure functions can be easily observed through the household behaviors, the correlation between the functions of indirect utility and expenditure can help convert Equation (1) into the expenditure function below:

$$E = E(P_X, P, Q, U^0) \tag{2}$$

Under the assumptions of a fixed utility level (U^0) and a constant price for X (P_X), the interaction between P and Q can be reflected through the expenditure function. As proposed by Bradford (1970) in his individual bid curve theory, a certain trade-off exists between the rise in the prices of domestic rice products and the multifunctionality values of paddy fields and thus creates the bid curve E^0, as shown in *Figure 1*. In other words, putting up with high prices of domestically produced rice products is necessary if paddy fields are to be maintained, as well as the multifunctionality benefit of paddy fields is to be enjoyed. As a result, the bid curve will stretch from the third quadrant to the first on the coordinate plane. The origin A (Q^0, P^0) in the diagram below denotes the current levels of rice price and multifunctionality benefit of paddy fields face consumers.

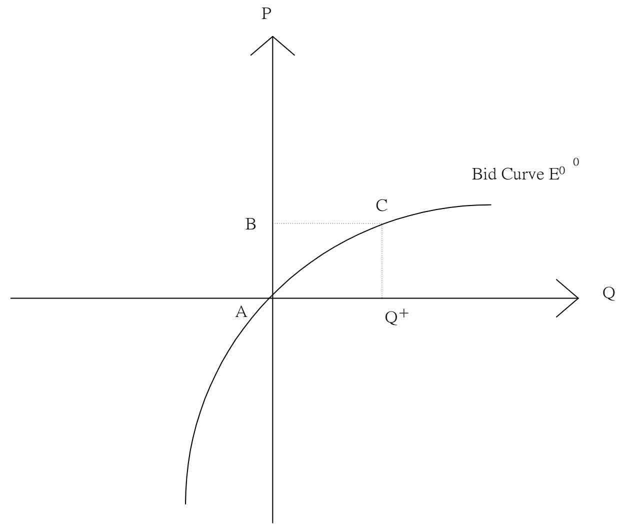


Figure 1 Bid Curve

The multifunctionality benefit of paddy fields increases as the axis of abscissa extends to the right and decreases as it moves to the left; the price of domestic agricultural products rises as the axis of ordinate stretches upward and drops as it goes down. Therefore, any given point along the Bid Curve E^0 will generate the same level of utility, making the bid curve the consumer's indifference curve between the environmental benefit and the agricultural prices. When the environmental function improves and reaches a higher level of Q^+, consumers' willingness-to-pay (WTP) equals the difference between the later price and the original price, or the result of P^1 minus P^0, or CQ^+ in the diagram. This is also called the compensating surplus (CS) for consumers. CS denotes consumers' WTP to maintain the original bid level of E^0 if they are to enjoy a better environmental benefit level of Q^+ as the environmental benefit changes, expressed in the function of expenditure below.

$$E(Q^0, P^0) = E^0$$
$$= E(Q^+, P^0 - CS) = E(Q^+, P^0 - WTP) \quad (3)$$

The questionnaire of this study is designed to estimate the respondents' bid function B (Q^0,Q^1,U^0,W) in response to the restored environmental benefit of agriculture in the hypothetical market as the economic benefit of environmental protection improves as shown below.

$$B(Q^0, Q^1, U^0, W) = E(Q^0, U^0, W) - E(Q^1,U^0,W) \quad (4)$$

In other words, the bid function is the difference between two expenditure functions,

$$W = W(P,P_X,V) \quad (5)$$

Where the independent variable V is the vector of the individual socio-economic characteristics. The bid function can be approached in two ways: One, according to Cameron & James (1987) and assuming u takes the form of normal distribution with the mean of 0 and variation of σ, the bid function may be approached by the probit model. Two, according to Cameron (1988) and assuming u takes the form of logistic distribution, the bid function can be approached by the logistic model. The two methods generate similar coefficients, but different scaling (Greene, 2000).

3. Questionnaire Design and Survey Sampling

The purpose of this article is to assess the preference structure and the relative balance scale of our people that are derived from the food, environmental, and cultural benefits in rice production. Another purpose is to perform the monetization on the overall production value from paddy fields, including market goods and non-market goods, in order to calculate the green GDP from rice production. Contingent Valuation Method (CVM) and Analytic Network Process method (ANP) all rely on the questionnaire method to collect the spiritual values, economic values, and the preference structure from the respondents.

The respondents should have prior knowledge about the event to be evaluated; this study used purposive sampling method to select the samples. We select the experts in the operational implementation or research of the field of multifunctionality of paddy fields and rice production to accompany us in our survey.

The value assessment in conjunction with CVM and ANP is associated with the willingness to pay, i.e. dollar amounts that are paid from the expert group whose members are currently not engaged in the rice-growing business. The first group of the expert is defined as a group of experts not related to the rice production businesses. However, for people in the operational implementation or research of paddy fields working for the Water Resources Agency, or the middle-to-top level management of the Council of Agriculture, or scholars from the water conservancy, or from the agricultural economics field are defined as "experts not involved in the operation of agricultural business."

The second group of experts is defined as "experts involved in the operation of agricultural businesses, who are members of the Irrigation Associations. The sampling of ANP is from the first and second groups. The sampling of conjunction Analytic with CVM and ANP is from the first groups.

We use the mail survey, in generally; the response rate of mail survey is very low. However, because selected experts are all concerned about this issue in the research, and the research team has adopted an intensive persuasion approach by telephone call, so the ratio of mail reply to the questionnaires is almost 60%, and after sorting out the invalid ones, the ratio of effective questionnaires is still more than 40%. Sampling design, questionnaire schedule, response rate of this questionnaire survey, shown in Table1.

Table 1： Survey Sampling and response rate

Respondents' Grouping	*experts involved in the operation of agricultural businesses*	*experts not involved in the operation of agricultural business*
Questionnaire design	ANP	ANP+CVM
Survey Period	8/10/09-9/10/09	8/10/09-9/10/09
Questionnaire	660	273
Return questionnaires	400	159
Return Rate (%)	60.61	58.24
Valid Samples	345	115
Response rate (%)	52.27	42.12

Source: Questionnaire survey of this study

About the questionnaire design, the first page of the questionnaire provides the basic information about the multifunctionality aspects of rice production, but the first question of the questionnaire is to examine the cognition and attention of respondents concerning the multifunctionality aspects of rice production.

The second question of the questionnaires is to use 2x2 pair-wise comparisons to obtain the respondents' preference structure with regard to the multifunctionality of paddy field.

The third question of the questionnaire is related to the Contingent Valuation Method. Supposing the agricultural free trade agreement affects the food, environment, and culture functions of paddy field, causing the original benefits to be reduced by 5%, but if the people of Taiwan are willingness to pay a little more money to buy Taiwan-grown rice, this will enable Taiwan to restore the multifunctionality of rice production back to its original environment. We ask the respondents: If the price of same quality Taiwan rice for each Taiwanese kilo is higher than imported rice by ____NTD, are you still willingness to buy Taiwan-grown rice, so as to allow the multifunctionality of paddy fields environment to be restored by 5% back to the present level? For the dollar amount, the questionnaire has provided 15 different amounts for the respondent to pick. The last part of the questionnaire is to ask the respondents about the socio-economic variables to facilitate the data Analysis.

4. Empirical Results

4.1. Contingent Valuation Method

Under the postulate of a linear bid function and with the help of the LIMDEP software package, the multifunctionality benefit of paddy fields as perceived by the respondents under the scenarios can be easily obtained. The results of the multifunctionality benefit of paddy fields given by experts not involved in the operation of agricultural business are summarized in Table 2. Among various individual variables, all t-ratios are significant. The correct prediction of the empirical models is 90.435%. On the whole, the Chi-square test confirms that the models reach a level of significance.

The factors in the bid function that have a higher significance level include WTP (The cutoff points of the WTP), VA(pay attention to benefits from Production values), VB(pay attention to benefits from Food safety and reliance values),VC(pay attention to benefits from cultural heritage and community development values), EDU(The respondent's education attainment), EXP(Regular monthly expenditure of the responding household). This echoes to the conclusion that cognition variables of the respondents are variables of significance made by most previous literature on CVM evaluation. Moreover, the respondent's expenditure level also plays an important role in his price bid, which is also consistent with the assumptions of the model.

Under the scenario of the respective arable paddy land decrease rate of 5%, all to be restored later, the respondents' willingness to pay for the multifunctionality of paddy fields was 108.64 N.T. from 1kg of rice (N.T. /Kg/rice).

Table 2: Empirical Results of CVM

PROBIT Model	*Coeff.*	*Std.Err.*	*t-ratio*	*P-value*
ONE (a constant term)	-6.1483	2.4293	-2.5309	0.0114
WTP (The cutoff points of the WTP)	-0.0293	0.0251	-1.1665*	0.2434
VA (pay attention to benefits from Production values)	2.8309	1.8512	1.5293**	0.1262
VB (pay attention to benefits from Food safety and reliance values)	3.8043	1.6129	2.3587***	0.0183
VC (pay attention to benefits from cultural heritage and community development values)	7.9254	3.9100	2.0270***	0.0427
EDU (The respondent's education attainment)	0.6130	0.2821	2.1728***	0.0298
EXP (Regular monthly expenditure of the responding household)	0.2441	0.1039	2.3497***	0.0188
Number of observations	115			
Restricted log likelihood	-38.4712			
Correct prediction	90.435%			
willingness to pay （WTP） for the multifunctionality of paddy fields. (N.T./Kg/rice)	108.64			

note：1.* is reach 75% significance level, ** is reach 90% significance level, *** is reach 95% significance level

Source: Questionnaire survey of this study.

4.2. Analytic Network Procedures

Therefore, our research uses the Analytic Network Procedures (ANP) to modify the valuation results. The empirical results shown in Table 3, Table 4, and Table 5. The difference between "experts involved in the operation of agricultural businesses" and "experts involved in the operation of agricultural businesses experts not involved in the operation of agricultural business" in the preferences structure is that experts involved in the operation of agricultural businesses are more preference in rice production. There is little difference in food safety and reliance values, cultural heritage and community development values, recreation and landscape values, environmental conservation values.

On the aggregate, the survey result shown that the relative weight scales of the people's preference is 1) benefits from production values is 21.03%, 2) benefits from food safety and reliance is 32.06%, 3) benefits from cultural heritage and community development is 12.58%, 4) benefits from recreation and landscape is11.59%, and 5) benefits from environmental conservation is 22.76%. We can find that the experts thought that the benefits from food safety and reliance are the most important benefits of paddy field in Taiwan. A partial explanation for this may lie in the fact that the changing climate and the special political affairs in Taiwan. In conclusion, the preference structure of the relative weight scales of market good(the benefits from the production values) are 21.03%,the non-market good are 78.97%.

Table 3: The preferences structure of experts involved in the operation of agricultural businesses

Benefits Ratio	Mean	Std.Dev.	Minimum	Maximum	NumCases
Production values	0.2275	0.1285	0.0250	0.6920	345
Food safety and reliance values	0.3062	0.1362	0.0310	0.6920	345
cultural heritage and community development values	0.1272	0.0692	0.0180	0.6240	345
Recreation and landscape values	0.1181	0.0625	0.0240	0.3680	345
Environmental conservation values	0.2210	0.1174	0.0180	0.6560	345
Total	1	-	-	-	-

Source: Questionnaire survey of this study.

Table 4: The preferences structure of experts not involved in the operation of agricultural business

Benefits Ratio	Mean	Std.Dev.	Minimum	Maximum	NumCases
Production values	0.1930	0.1242	0.0250	0.6450	115
Food safety and reliance values	0.3349	0.1445	0.0330	0.6920	115
cultural heritage and community development values	0.1244	0.0637	0.0300	0.3110	115
Recreation and landscape values	0.1136	0.0673	0.0190	0.3140	115
Environmental conservation values	0.2342	0.1201	0.0340	0.5250	115
Total	1	-	-	-	-

Source: Questionnaire survey of this study.

Table 5: experts involved in the operation of agricultural businesses and experts not involved in the operation of agricultural business

Benefits Ratio	*experts involved in the operation of agricultural businesses*	*experts not involved in the operation of agricultural business*	*aggregate*
Production values	0.2275	0.1930	0.2103
Food safety and reliance values	0.3062	0.3349	0.3206
cultural heritage and community development values	0.1272	0.1244	0.1258
Recreation and landscape values	0.1181	0.1136	0.1159
Environmental conservation values	0.2210	0.2342	0.2276
Total	1	1	1

Source: Questionnaire survey of this study.

4.3. Conjunction evaluation method of Contingent Valuation Method and Analytic Network Procedures

This study attempted to use the benefit and value assessment method, in conjunction with Contingent Valuation Method (CVM) and Analytic Network Procedures (ANP), and through the use of survey questionnaires, to assess the preference structure and relative weight scales of the people for the environmental and production output benefits that are derived from paddy fields. The monetization of the value of the multifunctionality of paddy fields are as below:1) benefits from production values are 22.85 N.T from 1kg of rice, 2) benefits from food safety and reliance are 34.83 N.T from 1kg of rice, 3) benefits from cultural heritage and community development are13.67 N.T from 1kg of rice, 4) benefits from recreation and landscape are 12.59 N.T from 1kg of rice, and 5) benefits from environmental conservation are 24.73N.T from 1kg of rice , shown in Table 6. The ratio of nonmarket/rice production is 3.756, shown in Table 7.

These benefits from the production values are the source of GDP of rice production. These benefits from all of the five categories are the source of Green GDP of rice production. This study calculated the GGDP of rice production which included market price of rice production and non-market value of multifunctionality of paddy fields that generated 158 billion NTD in 2008. The ratio of rice production output over real production output ratio, as designed by our study, obtained a result close to 1, showing that the benefit assessment for market goods and non-market goods, in conjunction with ANP and CVM, has been a reliable assessment method, therefore it shall be further promoted in the future.

Table 6: Empirical Results of conjunction evaluation method

Benefits (NT/Kg)	*experts involved in the operation of agricultural businesses*	*experts not involved in the operation of agricultural business*	aggregate
Production values	24.72	20.97	22.85
Food safety and reliance values	33.26	36.38	34.83
cultural heritage and community development values	13.82	13.51	13.67
Recreation and landscape values	12.83	12.34	12.59
Environmental conservation values	24.01	25.44	24.73
Total *(NT/Kg)*	108.64	108.64	108.64

Source: Questionnaire survey of this study.

Table 7:The ratios of nonmarket/rice production

ratios	*experts involved in the operation of agricultural businesses*	*experts not involved in the operation of agricultural business*	aggregate
Production values	1	1	1
The ratios of Food safety and reliance values / Production values	1.345934	1.735233	1.524489
The ratios of cultural heritage and community development values / Production values	0.559121	0.64456	0.598193
The ratios of Recreation and landscape values / Production values	0.519121	0.588601	0.551117
The ratios of Environmental conservation values / Production values	0.971429	1.213472	1.082263
The ratios of GGDP of Paddy field production / Production values	4.395604	5.181865	4.756063
The ratios of nonmarket value of multi-functionality of paddy field / Production values	3.395604	4.181865	3.756063

Source: Questionnaire survey of this study.

Table 8: GGDP of Paddy production

GGDP of Paddy production	*Use 2008 gap of Paddy production to calculate GGDP (.a thousand N.t)*	*use WTP to calculate(108.64N.t/Kg) GGDP (.a thousand N.t)*	WTP/Real GDP
Production values	31,362,747	33,291,350	1.061493
Food safety and reliance values	44,197,348	50,752,291	-
cultural heritage and community development values	17,342,565	19,914,654	-
Recreation and landscape values	15,977,768	18,347,444	-
Environmental conservation values	31,376,532	36,030,011	-
GGDP of Paddy field production	140,256,961	158,335,752	-

Source: Questionnaire survey of this study.

5. Conclusion and Recommendation

This study attempted to use the benefit and value assessment method, in conjunction with Contingent Valuation Method (CVM) and Analytic Network Procedures (ANP), and through the use of survey questionnaires, to assess the preference structure and relative weight scales of the people for the environmental and production output benefits that are derived from paddy fields. The monetization of the cost of total production output from paddy fields included two important production factors, market goods and non-market goods. This study calculated the GGDP of rice production which included market price of rice production and non-market value of multifunctionality of paddy fields that generated 158 billion NTD in 2008. The ratio of rice production output over real production output ratio, as designed by our study, obtained a result close to 1, showing that the benefit assessment for market goods and non-market goods, in conjunction with ANP and CVM, has been a reliable assessment method, therefore it shall be further promoted in the future.

6. Reference

Aizaki Hideo, Kazuo Sato, Hiroshi Osari (2006) Contingent Valuation Approach in Measuring the Multifunctionality of Agriculture and Rural Areas in Japan. Paddy and Water Environment. (2006)4:217-222.

Asian Regional Working Group (ASRWG), International Commission on Irrigation and Drainage,(2006) Multiple Roles and Diversity of Irrigation Water - Water and Eco-agriculture for Bio and Cultural Diversity .

Chang Koyin, Yung-hsiang Ying (2005) External Benefits of Preserving Agricultural Land: Taiwan's Rice Fields. The Social Science Journal 42(2005):285-293.

Chapagain A. K., A. Y. Hoekstra(2004), Water Footprints of Nations. Institute for Water Education.

Chiueh, Ya-wen, Ming-chien Chen, 2008。Multifunctionality of paddy fields in Taiwan- an Application of Contingent Valuation Method, Paddy and Water Environment, (2008) 6: pp 229-236.

Chiueh, Ya-wen, ，2002。The GGDP of Agricultural Sector in Taiwan, Taiwan Research Institution.

Kim Tai-Cheol, Uhn-Soon Gim, Jin Soo Kim, Dae-Sik Kim (2006) The Multi-Functionality of Paddy Farming in Korea. Paddy and Water Environment.(2006)4:169-179.

Saaty, Thomas L. (2008) The Encyclicon, Volume 2: A Dictionary of Complex Decisions using the Analytic Network Process, with Brady Cillo, ISBN 1-888603-09-7, RWS.

Structure of Nature Conservation Governance and Its Change, with the Shiretoko World Heritage Site as an Example

Kohei FUJII*
*Graduate School of Art and Sciences, the University of Tokyo

1. Introduction

Shiretoko was inscribed on the World Heritage List at the 29th Session of the World Heritage Committee in Durban, South Africa in July 2005. Shiretoko was the third World Natural Heritage site in Japan after the addition of Yakushima and Shirakami Sanchi in 1993.

A nature conservation policy had been implemented In the Shiretoko region prior to the World Heritage listing, mainly by the local government there, Shari Town. Some of the previous research on that focuses on nature conservation governance in Shiretoko includes that analyzing the trust movement “Shiretoko 100 m² movement,” and that analyzing the new governance structure, after designation as a World Natural Heritage site, such as the regional liaison councils and scientific committees built mainly around the Ministry of the Environment, the Forestry Agency, and Hokkaido.

But despite that accumulation of research, there is little research focusing on the historical development of movements and policies, and analyzing nature conservation governance in the Shiretoko region from the perspective of “institutional change.” One could say that the structure of current nature conservation governance is strongly determined by the process of historical change in institutions, and that the change characterizes the very structure of governance.

Under this concern for the issue, the purpose of this study is to take up the case of nature conservation governance in Hokkaido’s Shiretoko region, which involves a wide variety of actors, conduct a structural analysis which focuses on its historical and institutional change, and by this means get a glimpse of the structure of nature conservation governance, and by extension, environmental governance. Additionally, this study attempts to reassess the place of the above-mentioned previous research in terms of the “institutional change” view, which emphasizes the importance of history.

The main analysis methods were interviews of public actors such as those in Shari Town, Hokkaido prefectural government, Environment Ministry, and Forestry Agency, and detailed examination of documentary sources and the Shari Town history. Having performed these with great care, I explored interactions among actors, and institutional change due to internal and external factors.

2. The Development of Nature Conservation Governance in Shiretoko

2-1 Geographical Overview of the Shiretoko Region

Shiretoko is a peninsula in eastern Hokkaido that faces the Sea of Okhotsk. Its central portion is a volcanic zone that features a string of mountains in the 1,000–1,500 m range, including Mt. Shiretoko, Mt. Rausu, and Mt. Unabetsu. The volcanic zone is the border between the north, governed by Shari Town in Shari County, and the south, governed by Rausu Town in Menashi County. The Shiretoko region still has wildlife and wilderness, of which little remains in Hokkaido. The area from the peninsula's central part to the tip of Cape Shiretoko is listed as a World Natural Heritage site.

2-2 Institutional Framework for Nature Conservation in the Shiretoko Region

Because of Shiretoko's natural environment, which still features much wildlife and wilderness, it is protected by various laws as shown in Table 1. Primarily, Shiretoko National Park was designated in 1964 under the Natural Parks Law, and in 1980 the Mt. Onnebetsu area in central Shiretoko was designated a Wilderness Area. Additionally, in 1990 the Forestry Agency designated a broad area as the Shiretoko Forest Ecosystem Reserve, but it coincides closely with the area designated as a national park. As this shows, the Shiretoko region nature conservation system comprises diverse parts, but it is inadequate in the sense of system consistency and rationality as seen in, for example, some overlap in designated areas under the control of different government agencies.

Table 1. Nature Conservation System for Shiretoko under the National Government and Hokkaido, Excluding World Natural Heritage Listings

Item	Related law or other legal provision	Year designated	Designated area size(ha)	Controlling authority
Shiretoko National Park	Natural Parks Law	1964	53,415	Environment Ministry
Mt. Onnebetsu Wilderness Area	Nature Conservation Law	1980	1,895	Environment Ministry
Shiretoko National Wildlife Refuge	Wildlife Preservation and Game Act	1982	44,053	Environment Ministry
Shiretoko Forest Ecosystem Protection Area	Management Rules on National Forest Land	1990	35,527	Forestry Agency
Abashiri Quasi-National Park	Natural Parks Law	1958	37,261	Hokkaido
Sharidake Prefectural Natural Park	Hokkaido Natural Parks Ordinance	1980	2,980	Hokkaido
Natural monuments	Law for the Protection of Cultural Properties	—	—	Cultural Affairs Agency

Source: "Nature Conservation Initiatives in Shari Town" (Shari Town Environmental Conservation Section), with modifications by the author.

2-3 Development of Nature Conservation Policy Under Shari Town Guidance: Nature Conservation Ordinance and Shiretoko 100 m² Movement

As we saw in section 2-2, the national government (Environment Ministry and Forestry Agency) and Hokkaido exercise legal control over Shiretoko's natural environment, but in 1964 when Shiretoko National Park was designated under the Natural Parks Law, the management system was inadequate, so that even if the national government designated a park under the law, no specific measures were taken in particular. For that reason Shari Town, the concerned municipality, worked out measures to conserve the "pristine condition," which was an important element of national park designation. Starting with development of the First Shari Town Integrated Plan (1971), which set forth the town precept of "harmony of nature and humans," in 1972 it enacted the "Shari Town Nature Conservation Ordinance." It is said that this was the first instance of a town- or village-level local government enacting an ordinance for nature conservation, and the reason for its enactment was explained as follows by then Mayor Fujiya: "The park management systems of the national and Hokkaido governments are quite inadequate, so to cover that inadequacy it's important that local citizens assume a stance of solidarity" (Shari Town History [2004:1155]). In other words, the nation's first nature conservation ordinance was not a active exhortation by Shari Town, but rather a provision enacted reluctantly by the local municipality, Shari Town, because it had to assume the role of nature conservation owing to the lack of adequate management systems among superior-level actors, who are supposed to actively provide for nature conservation.

Even after enactment of the nature conservation ordinance, Shari town led the implementation of Shiretoko nature conservation policies in various ways. For example, in 1974 the "Society for Protecting the Blue Sea and the Forests" was founded. This was the precursor of the current Shiretoko Nature Conservation Society. And in September of the same year, Shari Town and Rausu Town collaborated in creating the "Shiretoko Charter," which is basically meant to facilitate the conservation and orderly use of Shiretoko National Park.

Further, a unique policy implemented by Shari Town is the Shiretoko 100 m² Movement, launched in 1977. Because there are many case studies and much prior research on this movement,[1] which is Japan's first municipality-led trust movement, this paper will omit a detailed description, but from the perspective of interaction among actors involved in nature conservation governance, the inception of the 100 m² movement lies in the failure of dialog between Shari Town and the then Environment Agency.

During the nationwide land speculation boom from 1965 to 1975, real estate dealers obtained, by 1974, 282 ha of Shiretoko Peninsula land given up by farmers (Shari Town History [2004:1184]). Seeing a crisis situation, Shari Town changed the designation of a zone of abandoned farmland within the national park and danger of development from type 3 special

[1] See, for example, Kazuo Tatsuno [2010], *Come Back, Shiretoko! The Dream of the 100 m² Movement*, Asahi Shimbun Publications Inc.

area[2] to type 1 special area, which imposed strict limitations, and negotiated with the Environment Agency to have the land marked for purchase by the government. However, there was a legal barrier in which the purchase of land once made into farmland would not allow designation as a type 1 protected area, and therefore negotiations with the Environment Agency failed.[3] The solution that then Mayor Fujiya came up with was purchase of the land by a national trust movement. The Shiretoko 100 m² Movement, launched in 1977, induced a response throughout the country (Shari Town History [2004:1186]), and a Shari Town pursued a unique nature conservation policy that included legal provisions such as the 1978 enactment of the "Ordinance on Creating Natural Landscape Conservation Forests" and the "Ordinance on a Fund for Land Conservation in Shiretoko National Park."

In sum, in the 1960s and 1970s there was a situation in which a national park was designated under the National Parks Law, but as there was effectively no involvement of higher-echelon authorities, Shari Town had to carry the entire burden of nature conservation policy. Owing to the lack of active involvement by higher-echelon authorities the enactment of nature conservation ordinances or in implementation of the Shiretoko 100 m² Movement, which are regarded as pioneering initiatives, Shari Town was obliged to take on these tasks.

2-4 Shari Town's Relationship with Higher-Echelon Authorities: Nature Conservation Policy Transition Period

With the arrival of the 1980s, various problems started emerging in Shiretoko. In particular, there was an evident clash between higher-echelon authorities and Shari Town, which had singlehandedly assumed the burden of nature conservation policy.

A clash between Shari Town and the Forestry Agency that can be cited is the issue of logging in a national forest. In 1981 the agency came up with a plan to log about 20%, or 26,000 m^3 of the 1,300-ha Shiretoko National Forest, and for that purpose build a new 12-km logging road. Shari Town asked the agency to reconsider the plan from the viewpoints of environmental damage from road building and impacts on the fishing industry from river

[2] Type 1 through type 3 special areas are established in parks under the Natural Parks Law to maintain parks' scenic beauty. Type 1 special areas are defined as "areas among special areas with the greatest need to maintain scenic beauty, where it is necessary to protect the current landscapes to the maximum," thereby imposing strict limitations on development. By contrast, type 3 special areas are defined as "areas where in general there is little concern about impacts on maintaining scenic beauty, especially with regard to ordinary farming, forestry, and fishing activities," thereby leaving open the possibility of development if nothing were done. For that reason Shari Town appealed to the Environment Agency to raise the designation of the zone of abandoned farmland.

[3] Additionally, settlers whose only asset was their farmland wanted to dispose of it at favorable conditions and obtain income. Therefore many of them sold their land to real estate agents (Shari Town History [2004:1184]).

pollution, which led the agency to temporarily set the plan aside (Shari Town History [2004:1174]). Subsequently in 1985 when the Fifth National Forest Management Plan Draft[4] was presented to Shari Town, nature conservations groups strongly objected, so Shari Town became a mediator in talks between the Forestry Agency and conservation groups, but the agency held fast to the position that it would study the situation while carrying out logging. Shari Town asked the agency to hold off on logging and conduct a scientific investigation. The then Environment Agency director-general also toured the site, and logging was temporarily frozen. In 1987, however, the Forestry Agency logged part of the national forest despite objections, which elicited vehement opposition from nature conservation groups, local tourism business, and other parties. This forced the Forestry Agency to give up further logging. Subsequently the agency indicated it had changed its approach, and it considered ways to conserve and manage forests in response to the challenge of balancing forestry with nature conservation in national forests. Later the agency created 12 “forest ecosystem protection areas” throughout the country.

An example of a clash between Shari Town and the Environment Agency is the measures for the rational use of automobiles in national parks. In 1991 the Environment Agency set up the Utoro Management Office, which had long been requested. Once this link with the agency had finally been established in Shiretoko, the “Preparatory Committee of Involved Agencies on the Implementation of Measures for the Rational Use of Automobiles” was launched around the nucleus of the Environment Agency. But owing to schedule changes by the Environment Agency, the committee never had more than the first two meetings. Because the situation was going nowhere in Shari Town, it considered implementing its own measures, but circumstances made it difficult to get local understanding. After repeated requests by Shari Town to the Environment Agency, the committee was revived in August 1995, but Shari Town had caustic criticism for the agency’s attitude, saying that “the more than four-year interruption raises questions about the government’s negative attitude toward environmental administration” (Shari Town History [2004:1172]). Thereafter, with regard to measures for the immediate future, the committee worked on a rough draft by three parties — the Environment Agency, Hokkaido, and Shari Town — that was based on a tentative draft by Shari Town, and in 1999 restrictions were imposed on vehicular traffic on 12 km in the Kamuiwakka area.

2-5 Efforts Toward World Heritage Listing

With the inscription of Yakushima and Shirakami Sanchi as World Natural Heritage sites in 1993, Shari Town launched a study to determine the possibility of listing Shiretoko as well. A major reason for trying to get a World Natural Heritage listing is to elicit the cooperation and

[4] The plan called for cutting five or six trees per ha, for a total of about 20,000 m^3 in a forest area covering about 1,700 ha in the park, and having a management goal of making the forest younger by cutting old trees, and promoting the effective use of timber resources and the economic development of the local forestry industry.

involvement of local actors in Shiretoko's nature conservation (interview with a Shari Town office employee in charge of the matter (August 2009)). World Heritage presents a larger framework than national parks, and therefore the institutions for conservation are more substantial. In addition to substantiality, there is a need for the involvement of many different actors in the institutions, and the World Heritage framework makes it possible to elicit the involvement of higher-echelon authorities such as the Environment Ministry, Forestry Agency, and Hokkaido Prefecture, thereby creating a system enabling Shari Town, which had shouldered the burden by itself, to have other actors take on part of the burden. These could be considered the reasons that Shari Town initiated a study aimed at World Heritage listing.

Nothing happened for a time after starting the study, but in 1999 Shari Town and Rausu Town jointly held a "World Heritage Forum," after which Shari Town started asking the government to help with World Heritage listing. In response, efforts toward listing gradually increased on the national government level, such as with the Basic Concept for Appropriate Use of Shiretoko National Park, which the Environment Ministry issued in 2002. The park was one of the candidates for World Heritage listing chosen by the ministry in May 2003. In October 2003 the "Regional Liaison Council," whose office is run by the Environment Ministry, the Forestry Agency, and Hokkaido, held its first meeting, and in July 2004 the "Scientific Committee" held its first meeting. The committee's purpose is the adaptive management of the region's natural environment. And in July 2005 Shiretoko was inscribed on the World Natural Heritage list.

3. Analysis of Change in Shiretoko Nature Conservation Governance Structure

Section 2 presented a general overview of the course of events from national park designation to World Heritage listing. This section will make use of that in discussing change in the nature conservation governance structure for Shiretoko. To begin with nature conservation governance in Shiretoko can be divided into three main time periods: the 1960s and 1970s, the 1980s through the mid-1990s, and mid-1990s to the present.

During the first period — the 1960s and 1970s — Shiretoko's nature conservation policy was almost entirely carried out by Shari Town, the municipality to which Shiretoko belongs. Even though Shiretoko was designated a national park in 1964, the lack of any function in the national park system to control use made it impossible to elicit active involvement from the then Environment Agency. In interviews, employees of the Shiretoko Foundation and the Shari Town Nature Conservation Section gave testimony such as: "It used to be that municipalities were naturally expected to manage national parks, and the Environment Ministry would hardly do anything," and "Before the World Heritage listing, there was hardly any involvement in this region by the relevant government agencies." These statements corroborate this lack of government involvement. In other words, it was not a matter of Shari Town actively implementing nature conservation policy, but rather being obliged to do so owing to distrust of the national and Hokkaido governments because those higher-echelon authorities were shirking their obligations. One of the interviewed employees stated, "We somehow found the funds for management of the national park and government-designated wildlife refuges, and for the management of wildlife that Hokkaido was supposed to do, spending so much that we wondered why the town had to put so much of its general account budget into it.” As this shows, enactment of the Nature Conservation Ordinance, which was the first of its kind on the town/village level, implementation of the Shiretoko 100 m² Movement, a municipality-led trust movement, and other measures that could be considered pioneering examples even nationally, owe their existence to Shari Town being pressured by circumstances to carry out nature conservation.

After the period during which Shari Town carried out Shiretoko nature conservation policy on its own, the 1980s arrived, and as seen in the Section 2-4 overview, clashes between the town and higher-echelon agencies over nature conservation came to the fore. This time period corresponds to the second period covered by this analysis. While the lone nature conservation policy of Shari Town still accounted for most conservation efforts, the town had some success in gradually drawing out the involvement of higher-echelon authorities by means of conducting discussions with those authorities on individual nature conservation issues such as logging in national forests and policy the appropriate use of motor vehicles, thereby time and again applying persuasion for involvement in nature conservation. Some specific achievements are the creation of a forest ecosystem protection area by the Forestry Agency, building of a wildlife refuge management center by the Environment Agency, establishment of the Utoro Management Office, and initiatives by the Environment Agency and Hokkaido Prefecture to purchase private land. Although such initiatives could not be called active involvement, there was at least a difference with the 1960s and 1970s, which had a total lack of involvement. Thus one could argue that Shari Town’s active lobbying of the central government (Environment Agency and Forestry Agency) and Hokkaido Prefecture, which were hardly involved at all despite their expected role as actors involved in nature conservation governance, succeeded in eliciting a measure of involvement. In other words, persuasion efforts by Shari Town, an internal factor, can be considered to have induced gradual institutional change the structure of Shiretoko nature conservation governance. This is the second time period. However, the structure of nature conservation governance in the first and second time periods would be depicted in the same way in the sense that full-blown involvement of higher-echelon authorities had still not been elicited in the second period.

In the third period, starting in the mid-1990s, active involvement by the central and Hokkaido governments were seen in the bid for World Heritage listing. Inscription in the list made the three actors which implement laws — the Environment Ministry, Forestry Agency, and Hokkaido — into “World Heritage site managers,” and they came to play a central role that includes running the offices of the Regional Liaison Council and the Scientific Committee. While coordination of opinions and policies and management of World Heritage sites had previously been compartmentalized, having these three actors take over the offices greatly facilitated them and created an enabling environment for policy integration. And while Shari Town had until then implemented nature conservation policy on its own, this change enabled it to have higher-echelon authorities shoulder some of the responsibility within the World Natural Heritage framework.[5]

If one analyzes the structure of nature conservation governance for Shiretoko based on the historical course of events, a possible interpretation is that the World Natural Heritage institution is an external factor, and that the imposition of the World Natural Heritage framework forced institutional change. Because that framework requires an overall regional plan, the circumstances left no choice but path-dependent involvement by the Environment Ministry, Forestry Agency, and Hokkaido, but that is arguably because it was the active persuasion by Shari Town in the second period which created that path-dependent situation. If Shari Town, as an actor participating in governance, had not appealed to higher-echelon authorities, which were the other actors, and encouraged them to become involved, the higher-echelon authorities probably could not have created the foundation for path-dependent involvement.

4. Summation

This research uses the example of the Shiretoko region, in which various different actors are involved, to analyze the structure of nature conservation governance and its change from the perspective of historical institutional change. Shari Town has implemented most of the specific nature conservation policy for Shiretoko, but that was because it could not gain the cooperation of the relevant higher-echelon government authorities: the Environment Agency, Forestry Agency, and Hokkaido Prefecture, which compelled Shari Town to implement policy itself. But the reason that Shari Town was able to implement nature conservation policy for so many years is that the mayors gave nature conservation primary importance in town administration, and actively incorporated it. This too must be taken into account. At the same time, higher-echelon authorities such as the national and Hokkaido governments at first had little involvement, then starting in the 1980s started leaning toward nature conservation policy little by little under lobbying by Shari Town, but did not become heavily involved. However, amid that gradual change, and with the external imposition of a binding framework — inscription on the World Natural Heritage list, the three actors responsible for implementing laws fund themselves in a different situation that required their strong commitment to nature conservation governance for Shiretoko.

It has been said that nature conservation governance in Shiretoko underwent a major paradigm shift that was catalyzed by World Natural Heritage listing. But this research has shown that prior to listing interaction among the actors had already elicited the involvement of higher-echelon authorities. And because that internal and gradual institutional change was underway, the response to forced institutional change by an external factor, the World Heritage

[5] However, many people still insist that the role of the Environment Ministry, Forestry Agency, Hokkaido Prefecture, and other higher-echelon authorities is inadequate (for example, Yamanaka [2008]).

listing, was enabled in a path-dependent manner. Post-listing nature conservation governance appears at first glance to have a hierarchical structure in which higher-echelon authorities have one-sided authority, but the structure also enables Shari Town to be actively involved in policy owing to the historical course of events leading to listing. The example of Shiretoko, in which various actors of different types are involved, exhibits an environmental governance structure that is noteworthy from the perspectives of its multilevel nature and mutuality.

Acknowledgment: In writing this paper I conducted interviews with employees whose responsibilities included Shiretoko in Shari Town, the Shiretoko Foundation, Ministry of the Environment, Forestry Agency, and the Hokkaido prefectural government. I wish to express my sincere gratitude to all of them for making time for me in their busy schedules.

Citation

Hajime Nakagawa [2005]: "Development and nature conservation of Shiretoko peninsula," *Agriculture and economics*, vol.71, no.6: 31-38 (in Japanese).

Kazuo Tatsuno [2010]: *Come Back, Shiretoko! The Dream of the 100 m^2 Movement*, Asahi Shimbun Publications Inc..(in Japanese).

Masami Yamanaka [2008]: "Problem and the future of world natural heritage registration in Shiretoko national park," *Environment and pollution*, vol.38, no.2: 37-43 (in Japanese).

Noriko Ookubo [2008]: "Conservation and management system of natural heritage," *Environment and pollution,* vol.38, no.2: 16-22 (in Japanese).

Ryosuke Murata [2008]: "Change in Shiretoko in world natural heritage registration," *Global environment*, vol.13, 81-87 (in Japanese).

Shari Town [2004]: "Shari Town History" (in Japanese).

The Economic Impact from Agricultural Products Loss Caused by Natural Disasters and Regional Input-Output Analysis in Taiwan

Hsing-Chun Lin*,

Associate Professor, Department of Applied Economics, National Chiayi University

Tzu-Min Kao

Assistant professor, Department of Finance, Ming-Chuan University

Li-Chen Chou

Ph. D. Student, Department of Economics, National Chengchi University

Ching-Cheng Chang

Research Fellow, Institute of Economics, Academia Sinica, and Professor, Department of Agricultural Economics, National Taiwan University

ABSTRACT

Although Taiwan's agricultural production only accounts for less than 2% of total GDP, agriculture industry still plays an important role to support the development of other industries. However, during the production process, agriculture industry often suffers loss, in final production result and farming field and facility, caused by uncontrollable natural disasters. And transferred by the industrial linkage effect, this kind of production decrease impact will be seen on overall economy development output and employment in that particular region; moreover, this will also create agricultural product price fluctuation which will influence final consumer consumption. From the other aspect, in Taiwan we observed some obvious gap already exist in each regional agricultural production which resulted from the differences of the natural environment. Once these uncontrollable natural disasters happen, the direct and indirect impact on agricultural activities will also vary from region to region. Therefore, in this paper we try to apply Miller and Blair (1985) Input-Output model in supply side and the approach of Regional Input-Output analysis in order to evaluate all possible economic impact from products loss caused uncontrollable natural disasters for the last twelve years in Taiwan.

Keywords： Agriculture, Regional Input-Output Analysis, Natural Disaster, Products Losses

* Corresponding author. Associate Professor, Department of Applied Economics, National Chiayi University. 580 Sinmin Road, Chiayi, 600, Taiwan. E-mail: hclin@mail.ncyu.edu.tw.
Tel: 886-5-2732858. Fax: 886-5-2732853. Residual errors are ours alone.

I. Introduction

Agriculture usually encounters unpredictable natural disasters (like typhoon, earthquake etc), causing some damages such as agricultural products lost, farmland destructed, and facilities destroyed. The production declines once natural disasters occurred. Not only did it influence the whole economy of produce and employment demand, but it also caused the fluctuation of agricultural product price, affecting the entire folk consumption through the effect of the industry connection. On the other hand, the agriculture production of each district inside the country is subjected to the differences under natural conditions. The disparity of agriculture development among all regions is very obvious due to the reason. Therefore, this paper collects the disaster loses data from farm crops in the last ten years. We analysis its characteristic and distribute variety such that the production losses, farmland loss, facilities losses and conservation of water and soil. Among them, the study takes the production losses as the losses of supply side, and the farmland loss, facilities losses and conservation of water and soil belong to the losses of demand side. Due to the production losses proportion of agriculture is bigger and the indirect influence of the downstream industries, this article attempted to combine the supply side model of Miller and Blair (1985) and regional input-output analysis to evaluate the economic level influence that aims at the agriculture loss caused by natural disasters in recent years and how it might have impacted on regional and national economy.

II. Literature Review

Related studies about the natural disasters on the economic impact assessment, academic estimated systematically against natural disaster losses have been affected that post-disaster reconstruction and disaster prevention planning, animal and plant pests and pathogens by the invasion and other issues recently. Analysis of disaster losses usually can be divided into macroeconomic analysis and microeconomic analysis, the former followed with interests in a country or a state's GDP impact assessment, the latter concerned about the comparative level of inter-dynamic cost of natural disasters between different periods of time. The measurement methods of disasters on income and indirect effects include survey, econometric models, Box-Jenkins time series analysis, Input-Output model, Computational General Equilibrium model and Economic Accounting models. Although all kinds of methods have different advantages and disadvantages, Input-Output model can calculus direct and indirect effects of disaster losses and Regional Input-Output model have better accurate measures then national Input-Output model.

In order to explore the emphasize of Agro-ecosystems by climate change, Fischer *et al.* (2002) evaluated the development of economic system in the future by Basic Linked Systems (BLS) and Global Circulation Models (GCM). They analysis the affections of society and economic system developments in the future by the emphasis of climate change. Then the authors advised and explored emission strategies through a serious of models. The study indicated that climate changes influence all kinds of natural ecosystems and further change regional productivity and population growth in the long term. The conclusion showed there are 2,122 hectares of natural ecosystems reduces in the Arctic polar region of northern hemisphere due to the greenhouse effect by GCM evaluation.

Charlotte(2003) measure the potential impact index of disasters by macroeconomic side and conclude that the potential impact of disasters can be divided into the direct costs of physical losses, indirect costs of production losses, the second round or the overall affection in short run and the losses of long tern effect such as: government budget balance. The measurements of the potential impact of disasters include Growth Modeling, Partial Equilibrium Growth Modeling, Input-Output analysis, Social Accounting Matrices and Computational General Equilibrium analysis.

Clower(2005) claimed the assessment of the economic impact of natural disasters is important. Analysis of disaster losses usually can be divided into macro-economic and micro-economic analysis. The former focus on a country or at least one of the state's gross domestic product impact assessments, the latter targeted the natural disaster losses which include the dynamic comparative of inter-temporal costs at different times. The measurement methods about disasters on income and indirect effects include: survey, econometric model. Box-Jenkins time serious analysis, Input-Output model, Computational General Equilibrium model and Social Accounting Matrix. Various types of methods have different advantages and disadvantages: survey can offer the direct impact on disaster information but assist the error of non-response. The feasibility of econometric model need non-time difference data; Box-Jenkins time series analysis use ARIMA model usually, the model is based on past data for future prediction, though it is quite simple, but has a strong analytical.

Therefore, it is widely used in disaster assessment studies; Input-Output model can calculate the direct and indirect effects of disaster losses, and the accuracy of Regional Input-Output model higher than Input-Output model for national measurement. However, Input-Output model has the problem with static and linear analysis. Input-Output model can combine social accounting matrix to explore income distribution and transfer effect. Computational general equilibrium model can estimate direct and indirect effects like Input-Output model, but there are too complicated to analysis in regional. Social Accounting Matrix can combine other methods like survey or Input-Output model, but so difficult to measure labor capital.

Alam and Rolfe (2006) describe two kinds of economic model which evaluated the costs by pest and pathogen attack, i.e. Input-Output analysis and Computational General Equilibrium model. The advantages of Input-Output analysis not only estimate production factor side but also being caught up during the outbreak of a goods and services in an economic system and then reflect to demand and supply affections. Computational General Equilibrium model measures the economic losses of pest and pathogen attack by empirical data analysis. Input-Output model focus on direct and indirect effects and calculate the impacts of economic and society. Computational General Equilibrium model measure the losses of pest and pathogen attack then set the strategies to fix the environment. The authors indicated that the negative effects of pest and pathogen attack couldn't bear by some firms or producers, they suggested policy should strengthen the implementation of vendor self-quarantine, with the implementation of the policy of incentives, so that a more efficient implementation of policies.

There are a lot of literatures which used Regional Input-Output model to estimate losses of natural disasters. For instance, Tiebout (1969) calculated the relayed effects of regional industries in Washington State by Regional Input-Output model. Based on Tiebout's(1969) research, Jiang *et al.*(2005)evaluated the agricultural irrigation water and industrial water restrictions due to climate change of the formation of drought-induced economic losses.

Rose *et al.* (1997) estimated the industrial impacts by earthquake with Regional Input-Output and linear programming. Rose and Liao(2005)measured the related impacts with Computational General Equilibrium model for water supply system damage by earthquake. Gordon *et al.* (1998, 2004)estimated the transport damage by the earthquake simulation in south California and measured the direct and indirect costs of earthquake which integrated the Regional Input-Output model and the price model by Miller and Blair(1985). Yamano *et al.*(2007)explored the impacts on the regional industries where came from electricity and transport internet injuries that caused by natural disasters in Japan, they found direct damages exceed indirect damages a lot and the impacts of manufacturing and commercial districts worse than other areas.

Tsuchiya *et al.* (2007) analyzed the economic impacts of transportation system and infrastructure which faced Tokai-Tonankai earthquakes. The economic damage analysis based on Input-Output analysis and Computational General Equilibrium in the literature. The study expanded Computable General Equilibrium to Spatial

Computable General Equilibrium (SCGE) and simulated the paralysis and overloading levels of transpose, internet structure.

Donaghy *et al.* (2007) surveyed Marshallian Computable General Equilibrium (MCGE), Regional Econometric Input-Output Models (REIMs) and Sequential Interindustry Models (SIMs) in literature which analysis the impacts in economic system that cause by unpredicted events. They claimed REIMs can capture the intra-periods impact and the nonlinear continuous events in the process of restore.

Okuyama(2007) compared the advantages and disadvantages between Input-Output model, Computational General Equilibrium model and Social Account Matrix. In this study, the author considered that use a model to assess the economic impact mainly look at the accuracy level of the model. However, every disaster is not the same (unique) and cannot bring the same degree of hazard. This paper concluded the model evaluation should emphasize the theory and applied the economic theory to make empirical or simulated results which prevent overestimate or underestimate science inference.

There is few references concern this issue on Taiwan. Yang (1996) introduced Agro-meteorological disasters and the relationship of meteorological factors and rice productions briefly. Chen (1997) compiled statistics from 1954 to 1995 to the rice by typhoons, heavy rain, wind, cold damage, drought and other weather disasters. Above references only used statistics or regression analysis to explore the production of agro-meteorological disasters, the direct impact of the disaster losses arising from a product of industrial linkage effects, as well as regional agricultural development because of different circumstances does not explore.

Lu (2003) took typhoon Nari in Taipei City as an example to explore the loss of public facilities and flood control mechanism. First of all, in order to calculate the loss of all public facilities he use of public sector statistics and the use of flood control interview information,. Secondly, set up the questionnaire to explore the design of units of public facilities and the loss of flood disaster prevention mechanism for all. Wu (2003) evaluated how the reconstruction budget of the 921 Earthquake to influence on the industrial structure and the economic development of tourism in central Taiwan. Compared various related literatures and chose the RAS method with the least measurable error to set up the Regional Input-Output model and to assess the linkage contributions and the economic multiplier impacts.

III. Analysis of Taiwan’ s Agricultural Disasters Products Loss

According to Table 3-1 and 3-2, agricultural losses amounted to NT $149.2 billion totally and with an average annual NT $12.4 billion losses by natural disasters in nearly 12 years (1997-2008). The agricultural productions damage are the main disaster losses which accounted more than 50 percents except 1999 and 2001 years in whole period, there were more than 90% disaster losses in 2002 and 2003.

We further observed by divided the disaster losses into disasters, counties and cities and crops, then we found the top five major disasters: typhoons, heavy rain, hail, low temperature and chilling injury. The agricultural losses caused by typhoon and heavy rain surpassed 80% in the last decade in Table 3-3 (except 2002). Typhoons and heavy rain will happen almost every year because they go through the geographical position frequently where Taiwan located. Most of these disasters came from climate change, every kind of them occurred at the particular period. For example: typhoons often appeared in the summer and fall; chilling injury occurred in winter usually and hail happened between February to March. We can prevent these disaster losses if we combined the weather forecast and agricultural technical.

In Table 3-4 we observe Pingtung, Taichung, Kaohsiung, Changhua, Yunlin and Nantou County were the worst losses counties due to the proportion of agriculture outputs in these counties are higher than others. The largest losses in Pingtung in 1997, Changhua in 1998 and Taitung in 2000, mainly come from typhoon. The biggest factor that caused agricultural losses in Pingtung (1999) was chilling injury; Hail caused losses in Hsinchu (2002). Pests jeopardized the harvests in Taichung (2003) and the largest agricultural losses in Taichung due to heavy rain in 2006. Therefore, Even if the temperatures are higher in the southern region, the particular climate change like chilling injury still endangered harvests.

In Table 3-5, we can find the series losses included wax apple, mango, papaya, watermelon, pears, peaches, plums and other vegetables, both of them accounted nearly 60% in agriculture. For instance: the losses of peers in 1998, 2002 and 2003; the losses of wax apples in 1999 were all the worst losses in county.

According to the statistics of relief payments in household in Table 3-6, total payments were 17,341,500 thousand during 1998 to 2007 and accounted 20.6% in agriculture product losses. Therefore, government should take into account the local or regional single agricultural disaster losses and the stability of agricultural production and income for the subsidies and the scope of disaster losses in agriculture.

Table 3-1 Agricultural Disasters Estimated Loss ： 1997-2008

Units: millions NT$

Years	Losses in Crops, Livestock, Fish and Forest					Farms losses	Loss of Fishing Facilities	Loss of Livestock Facilities	Loss of soil and Water conservation	Loss of Farmland Water Conservancy facilities
	Total	Crops	Livestock	Fish	Forest					
1997	4,931,667	4,711,128	32,769	21,756	166,014	161,591	194,372	13,053	978,862	-
1998	12,693,151	12,183,775	73,577	384,794	51,005	754,956	178,990	138,436	934,432	-
1999	7,593,088	5,222,606	514,645	1,386,400	467,437	1,136,581	113,488	1,664,616	5,759,309	-
2000	10,521,288	9,893,857	107,300	304,022	216,109	1,080,932	259,877	405,956	2,096,946	-
2001	5,908,468	4,709,135	399,628	504,187	294,888	3,752,759	336,635	1,724,249	3,040,616	-
2002	1,143,673	1,081,348	3,126	42,127	17,072	63,246	20,108	18,028	22,148	-
2003	4,236,100	4,060,868	50,765	22,357	102,110	12,280	125,806	15,170	50	-
2004	7,022,146	5,262,149	185,045	1,383,934	191,061	1,303,864	876,165	1,438,516	1,364,101	-
2005	20,691,295	18215,290	364,190	1,857,258	254,557	294,620	185,748	501,043	2,547,862	703,055
2006	3,274,750	3,162,448	27,734	73,100	11,468	91,410	14,023	139,194	1,408,164	1,462,965
2007	11,069,356	10,637,125	104,869	281,278	46,084	173,480	235,905	259,652	2,375,735	631,867
2008	13,419,717	12,559,055	117,984	719,862	22,816	160,228	105,266	509,124	4,146,950	780,462

Data resource: Council of Agriculture (2009), 2008Yearly Report of Taiwan's Agriculture

Table 3-2 The Ratio of Disaster Products Losses ： 1997-2008

Units: millions NT$

Years	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total losses	6,280	14,700	16,267	14,365	14,763	1,267	4,389	12,005	24,924	6,391	14,746	19,122
Production losses	4,932	12,693	7,593	10,521	5,908	1,144	4,236	7,022	20,691	3,275	11,069	13,420
The Ratio of Production loses	0.79	0.86	0.47	0.73	0.40	0.90	0.97	0.58	0.83	0.51	0.75	0.70

Data resource is as same as table3-1

Table 3-3 Products Loss for Disasters ：1997-2008

Units: thousands NT$

Disasters	Total	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Typhoon	66,820,437	2,923,404	7,115,021	1,496,180	8,337,358	4,394,970	43,988	2,832,597	4,852,945	11,481,770	750,685	10,237,821	12,353,698
Heavy Rain	12,334,466	1,623,719	1,887,572	502,811	791,057	110,806	57,462	57,899	1,608	4,057,756	2,333,557	429,104	481,115
Hail	851,465		95,022				341,291	332,691			30,211	52,250	
Low Temperature	30,017											30,017	
Chilling Injury	3,685,205	20,933	3,082,910			1,794	498,215	59,927					21,426
Seismic	3,526,255								235,132	2,675,764	47,996	23,365	543,998
Drought	176,414	86,400		1,930,372			90,014						
Pest	3,250		3,250	1,293,243									
Frostbite	760,884	23,972						736,912					
Climate Anomalies	760,348				760,348								
Rain Haze	145,482								145,482				
Foehn	29,266											29,266	
High grafting pears Sui	102,269				5,094		50,378		26,939			3,753	16,105
Diseases	40,842							40,842					
Strong Winds and Heavy Rain	32,700	32,700											
Tornado	6,265											2,890	3,375
Strange	1,514											1,514	
Total	89,307,079	4,711,128	12,183,775	1,998,991	9,893,857	4,507,570	1,081,348	4,060,868	5,262,106	18,215,290	3,162,449	10,809,980	13,419,717

Data resource is as same as table3-1

Table 3-4 Products Loss for Disasters Between Counties and Cities ： 1997-2007

Units: thousands NT$

	Total	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total	7,861,1180	4,711,128	12,183,775	5,222,606	9,893,857	4,507,570	1,081,348	4,060,868	5,262,109	18,215,293	3,162,448	10,310,178
Taipei County	652,005	129,257	56,632	42,336	76,565	78,182		140,860	65,256	31,869	546	30,502
Yilan County	1,563,800	90,885	141,936	40,114	183,629	59,348	13,157	126,120	230,563	332,056	33,300	312,692
Taoyuan County	705,525	192,428	8,377	25,035	74,989	49,912			54,649	96,603	80,424	123,108
Hsinchu County	1,994,496	132,550	143,415	936	137,336	70,551	461,720	30,206	195,966	364,670	219,141	238,005
Miaoli County	6,072,820	465,806	1,332,787	199,438	410,574	148,205	59,000	40,980	361,738	1,717,273	377,689	959,330
Taichung County	10,382,143	115,695	1,620,967	169,162	1,960,969	487,555	306,597	1,341,840	656,746	1,952,747	754,571	1,015,294
Chang-hua County	6,832,170	157,880	2,189,050	18,195	455,205	191,002	1,675	7,501	660,041	1,743,362	185,197	1,223,062
Nantou County	6,355,891	154,725	258,534	1,422,909	795,436	470,022	66,275	501,454	578,443	1,176,463	256,715	674,915
Yunlin County	6,721,569	86,323	336,208	104,307	379,332	736,242	35,805		296,220	3,453,070	303,768	990,294
Chiayi County	4,310,318	96,815	816,243	39,050	345,343	308,105			297,545	1,220,650	126,425	1,060,142
Tainan County	4,344,603	235,407	541,369	85,818	466,648	217,461		6,830	259,095	1,446,844	148,173	936,958
Kaohsiung County	7,527,456	312,965	1,298,023	537,552	1,025,259	396,740	38,515	135,089	577,972	1,868,329	223,427	1,113,585
Pingtung County	10,483,498	1,973,307	1,841,167	2,156,212	425,943	170,104	24,803	1,087,067	334,671	1,518,108	154,445	797,671
Taitung County	5,799,600	512,336	855,613	80,238	1,809,636	404,571	58,559	546,107	182,690	529,224	106,663	713,963
Hualien County	3,689,253	32,700	651,135	108,842	1,219,857	480,362	4,591	90,359	377,293	538,478	129,729	55,907
Peng-hu County	116,480	5,600	12,755	836	23,273	62,021			1,520	415	6,352	3,708
Keelung City	18,353	500				2,586			12,000	3,267		
Hsinchu City	15,299	1,487	4,642		1,194	3,465	45		147	1,802	718	1,799
Taichung City	260,007	1,666	34,820	5,268		132,755	9,578		34,096	24,984	8,711	8,129
Chiayi City	79,553		,		3,949	3,981			7,364	34,620	1,626	28,013
Tainan City	280,202	12,796	40,102	16,278	61,974	17,138	1,028		18,524	54,317	37,944	20,101
Taipei City	149,461				34,914	17,262		6,455	59,570	31,260		
Kaohsiung City	5,861				1,832					1,029		3,000
Kinmen County	250,817			170,080						73,853	6,884	

Data resource is as same as table3-1

Table 3-5 Production Loss for Disasters Between Fruits and Vegetables ：
1997-2007

Units: thousands NT$

Crops	Total	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total	78,448,269	4,711,128	12,183,775	5,222,606	9,893,857	4,507,570	1,081,348	3,938,728	5,133,993	18,000,772	3,137,993	10,636,499
Other fruits	3,2919,929	1,384,937	5,906,214	2,680,952	5,097,784	1,178,331	286,194	2,477,727	1,909,824	6,434,855	1,387,800	4,175,311
Other vegetables	12,727,639	757,059	2,002,670	549,830	1,288,582	1,437,087	23,186	574,201	1,035,616	2,860,065	633,180	1,566,163
Rice	7,886,355	278,036	1,501,415	115,660	528,869	403,007	15,738	34,564	417,804	2,541,061	184,512	1,865,689
Citrus	5,853,567	661,063	342,001	49,513	759,477	240,796	628,161	96,868	301,132	1,252,041	304,715	1,217,800
Watermelon, melon	5,000,538	945,328	787,504	287,814	608,028	468,247	23,113	63,361	279,755	870,252	398,176	268,960
Banana	4,404,440	171,745	512,295	224,613	676,388	222,374	23,387	257,703	384,122	1,222,808	82,691	626,314
Flower	1,695,077	74,602	189,372	364,933	175,651	16,942	13,668	130,017	160,778	295,793	29,372	243,949
Tea	1,680,375	31,629	58,459	386,972	137,371	11,065	30,881	234,165	38,328	669,114	8,934	73,457
Bamboo shoots	1,514,641	75,903	63,809	39,314	102,429	63,004	16,725	10,937	119,766	873,331	11,306	138,117
Corn	1,127,769	59,143	244,967	61,677	162,786	95,379	3,327	33,982	79,148	267,794	9,594	109,972
Groundnut	700,717	8,463	168,622	1,473	52,662	45,936	3,975	286	51,623	196,487	35,244	135,946
Other Cereal Crops	575,698	41,320	99,104	139,634	19,555	67		1,182	121,138	100,094	33,562	20,042
Pineapple	568,239	8,431	17,494	30,101	51,059	82,729	2,050	19,236	35,671	238,671		82,797
Nut	528,628	76,883	2,665	274,096	37,845	128,946	6,460	1,166	567			
Sugar from sugar cane	492,157	129,003	165,718	1,280	147,835	47,731	590					
Sweet Potato	374,370		86,393	5,149	28,213	47,066	3,893	1,053	24,453	123,954	16,925	37,271
Mushroom	166,932			7,200					118,083	28,986		12,663
Other oil use, Beverages with crops	73,817	1,801	13,793	2,015	13,787	509			3,079	8,531	1,734	28,568
Asparagus	72,820	3,266	17,288	380	5,536	18,354			6,662	16,935	248	4,151
Tobacco	50,855								21,910			28,945
Other agricultural products, Processing crops	23,591								23,591			
Cereal crops Byproduct	4,703		3,760						943			
Soybean	2,748	2,516	232									
Other fiber crops	2,280							2,280				
Cultivation	384											384

Data resource is as same as table3-1

Note: Other fruits include Wax apple, mango, papaya, watermelon, pears, peaches and plums etc.

Table 3-6 Natural Disasters of Agricultural Households and the Amount of Money Assistance ：1998-2007

	Total	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Money Relief Househlod (1)	1,079,692	218,857	40,102	52,479	74,515	5,135	26,923	90,332	312,907	13,222	245,220
Relief Payments (Thousand NT$)(2)	17,341,500	1,832,725	752,147	983,877	829,900	137,978	1,039,412	1,689,736	5,653,908	336,883	4,084,934
Production Losses (Million NT$)(3)	84,155	12,693	7,593	10,521	5,908	1,144	4,236	7,022	20,691	3,275	11,069
Relief Payments(2) / Production Losses(3) (%)	20.6	14.4	9.9	9.4	14.0	12.1	24.5	24.1	27.3	10.3	36.9

Data Resource is as same as table3-1

VI. Regional Input-Output Model and Data Base

This study assumes outputs coefficient fixed with stable distribution, uses Regional Input-Output Table based on Lin and Kao (2008). We also reference to Miller and Blair (1985) on the Input-Output model of the impact of supply-side configuration. Use above descriptions we calculate outputs, income and employment effect of different industries by exogenous inputs decrease.

Regional Input-Output Table can be classified as competitive and noncompetitive. In competitive, we don't divide imports as different matrix in middle trade matrix. In contrary, in noncompetitive the imports must divide in two kinds of matrix.

According to total outputs equal to the net amounts of aggregate demand. The balance of goods accounts must satisfies:

$$X = AX + FD - IM \tag{4-1}$$

$$A = \begin{bmatrix} [(zd_{ij}^{II} + zm_{ij}^{II})/X_j^I] & \cdots & [(zd_{ij}^{IR} + zm_{ij}^{IR})/X_j^R] \\ \vdots & \ddots & \vdots \\ [(zd_{ij}^{RI} + zm_{ij}^{RI})/X_j^I] & \cdots & [(zd_{ij}^{RR} + zm_{ij}^{RR})/X_j^R] \end{bmatrix},$$

$$FD = \begin{bmatrix} [fd_{ij}^{II} + fm_{ij}^{II}] & \cdots & [fd_{ij}^{IR} + fm_{ij}^{IR}] \\ \vdots & \ddots & \vdots \\ [fd_{ij}^{RI} + fm_{ij}^{RI}] & \cdots & [fd_{ij}^{RR} + fm_{ij}^{RR}] \end{bmatrix}$$

n: number of industries; r represents number of regions; X is (nr)×1 output matrix; A is (nr)×(nr) middle input coefficient matrix; IM represents imports; z_d represents middle input of domestic product; z_m represents middle input of imports with area names R in superscript and outputs categories i in subscript and j represents industry category.

Due to the agricultural crop losses are classified to the losses of domestic products. The effect of product losses subtracts the input of imports by domestic spill-over effect. Considering the balance of domestic products, equation (4-1) can rewrite:

$$X = A^D X + FD^D \quad , \tag{4-2}$$

According to supply-side Input-Output model based on Miller and Blair (1985), total revenues in all kinds of industries equal to the costs of inputs. Total revenues are the valuation of productions; total costs include inter-mediate input plus primary input. The relationship of total revenues and total costs as follow:

$$\begin{aligned} X_1^R &= \sum_{S=1}^{R} (Z_{11}^{SR} + Z_{21}^{SR} + \Lambda + Z_{n1}^{SR}) + V_1^R \\ X_2^R &= \sum_{S=1}^{R} (Z_{12}^{SR} + Z_{22}^{SR} + \Lambda + Z_{n2}^{SR}) + V_2^R \quad , \qquad . \\ X_n^R &= \sum_{S=1}^{R} (Z_{1n}^{SR} + Z_{2n}^{SR} + \Lambda + Z_{nn}^{SR}) + V_n^R \end{aligned} \tag{4-3}$$

(Total revenues = middle input ＋ original input)

Superscript SR are the area names; Z is middle input. We can use matrix to descript:

$$X' = i'Z + V \quad , \tag{4-4}$$

X' is the transpose matrix of X, i represents nr×1 vector with element equal to 1.

Under the stability of output distribution we can calculate equation (4-6) derived from equation (4-5):

$$z_{ij}^{SR} \big/ X_i^R = \overrightarrow{a_{ij}^{SR}} \quad , \tag{4-5}$$

$$Z = \hat{X} \vec{A} \quad , \tag{4-6}$$

$\hat{X}$ is a diagonal matrix of regional industries, substitute (4-6) into (4-4) we can get:

$$X' = i'\hat{X}\vec{A} + V \quad , \tag{4-7}$$

Because $X' = i'\hat{X}$

$$X' = V(I - \vec{A})^{-1} \quad , \tag{4-8}$$

When a middle input or an original input changes in a sector, based on equation (4-8) we can solve a new output vector:

$$\Delta X' = \Delta V(I - \vec{A})^{-1} \quad , \tag{4-9}$$

Similarly, if we substitute Domestic Leontief's matrix $(I - \overrightarrow{A^D})^{-1}$ for Leontief matrix $(I - \vec{A})^{-1}$, we can rewrite equation (4-9):

$$\Delta X' = \Delta V(I - \overrightarrow{A^D})^{-1} , \tag{4-10}$$

Since the formation of natural disaster losses of agricultural production can be regarded as a temporary shortage of agriculture, caused some industries which use agricultural products as input elements facing a shortfall of supply-side shock. Therefore we combine supply-side Input-Output model and regional Input-Output analysis based on Miller and Blair(1985).

$$\Delta X' = \Delta V(I - \overrightarrow{A^D})^{-1} \quad , \tag{4-10}$$

V. Economic Impact Analysis

For convenient of follow-up analysis, this study merged 162 into 45 commodity industry sectors based on the categories of 2001 Taiwan Input-Output table and estimated the impact of agriculture losses by supply side Regional Input-Output analysis. We also simplify 23 counties to 4 areas. These 4 areas are north area (Yilan county, Keelung city, Taipei county, Taoyuan county, Hsinchu city and Hsinchu county), middle area (Miaoli county, Taichung county, Changhua county, Nantou county, Yunlin county), sourth area (hiayi county, Tainan county, Kaohsiung counties and Kaohsiung city, Pingtung county, Penghu county) and east area (Hualien county, Taitung county). We calculated crop disaster losses in counties and cities in table 5-1

From Table 5-2 Simulation results show that over the past 10 years, damage to crops caused by natural disasters cut, the production decreased from NT$1.7 to NT$27.1 billion, of which 2005 the highest annual output effects, the effect of the direct effect of the annual output is about 65%, indirect spill-over effects across the industries, about 35%, and output results in various regions to central and southern regions to reduce total production up to the two together accounting for output results, mainly due to central and southern Taiwan as the main agricultural production areas, but in 2000 detract from the central region since the effects of the production has been higher than the southern region. Results obtained by the department of output results and the impact of industrial value-added rate, which is about income effects and output results of the four as if with the current year's gross domestic product, compared to the regional input-output model to assess each year total income effect will detract from the economic growth rate has dropped from 0.02% to 0.28% between. The employment effect, the department by the output results and the impact of industrial employment-output ratio over the past 10 years, agriculture in total employment effect of loss-induced reduction of about from 1,556 to 25,429 persons, if it is the end of the year compared to the total labor force, based on the past 10 years of crop losses caused by natural disasters cut in full, as expected, affected by the assumptions, the resulting impact on the employment effects of the unemployment rate will rise from 0.014 to 0.235 percentage points.

Above results indicates the impact of disasters on GDP of 0.005% to 0.084%, came from direct and indirect effects by GDP calculation. Compared to last decade agriculture accounted for GDP ranged from 0.359% to 5.549%, therefore our research estimates reasonable.

Base on Input-Output analysis assumption, we further illustrated as followed: first, we assume agriculture losses caused middle and downstream industries inputs and products decrease. Table 5-2 represents outputs decrease include total effects of agriculture and other industries, include animal husbandry, food industry, beverage industry, tobacco, textile, and other chemical products manufacturing that use agricultural products as input elements. Second, Input-Output model assumes agriculture material input has no substitute goods. Third, in this study we estimate of regional input-output model, based on the assumptions that agricultural input can be used in inter-regional transfer. Therefore the simulation results of partition larger than non-partition ones.

Table 5-1 Crop Disaster Losses in Counties and Cities 1997-2007

Unit: millions NT$

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Taiwan(Total)	4,293	12,184	5,050	9,894	4,490	1,084	4,060	4,939	17,876	3,134	10,603
Taipei County	129	57	42	77	78	0	141	65	33	1	30
Yilan County	91	142	40	184	59	13	126	231	330	33	311
Taoyuan County	192	8	25	75	50	0	0	55	96	81	109
Hsinchu County	133	143	0	137	71	462	30	196	333	219	235
Miaoli County	47	1,333	199	411	148	59	41	37	1,715	378	957
Taichung County	116	1,621	169	1,961	488	307	1,342	657	1,942	754	1,011
Chang-hua County	158	2,189	18	455	191	2	8	660	1,736	186	1,223
Nantou County	155	259	1,423	795	470	66	501	578	1,172	257	665
Yunlin County	86	336	104	379	736	36	0	296	3,443	304	989
Chiayi County	97	816	39	345	308	0	0	298	1,208	126	1,017
Tainan County	235	541	86	467	217	0	7	259	1,381	139	907
Kaohsiung County	313	1,298	538	1,025	397	39	135	578	1,800	223	1,068
Pingtung County	1,973	1,841	2,156	426	170	25	1,087	335	1,484	141	751
Taitung County	512	856	80	1,810	405	59	546	183	529	107	713
Hualien County	33	651	109	1,220	480	5	90	377	528	130	553
Peng-hu County	6	13	1	23	62	0	0	2	0	6	4
Keelung City	1	0	0	0	3	0	0	12	2	0	0
Hsinchu City	1	5	0	1	3	0	0	0	2	0	2
Taichung City	2	35	5	0	133	10	0	34	25	9	8
Chiayi City	0	0	0	4	4	0	0	7	32	2	27
Tainan City	13	40	16	62	17	1	0	19	55	38	20
Taipei City	0	0	0	35	0	0	6	60	30	0	0
Kaohsiung City	0	0	0	2	0	0	0	0	0	0	3

Data resource is as same as table3-1

Note：In the table has been lost production each year belonging to the non-crops lose some deductions, therefore, a total loss is less than in other cities and counties in Table 3 of the total losses. The damage to crops from other counties and cities thousand dollars to millions of units existing at the time the end of poor, therefore, the information in Table 3-1, there is a discrepancy. Another Agricultural Statistics Annual Report each year status of crops, killed there and Statistics "agricultural facility" and other non-agricultural items, the definition does not match with the crop, this research has its own deletion, therefore, the amount of loss in Table 5-2 below Table 3-1.

Table 5-2 Regional Economic Losses Effect by Natural Disaster

Units: million NT$；person；%

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Outputs losses effect											
The northern region	810	632	230	807	454	677	448	902	1,388	523	1,111
The ratio of agriculture in the region	(3.2)	(2.4)	(1.6)	(5.9)	(3.3)	(6.0)	(4.5)	(7.8)	(10.5)	(4.0)	(8.2)
The middle region	912	9,230	2,916	6,361	3,147	786	3,086	3,559	14,882	2,932	7,474
(ratio)	(0.7)	(7.4)	(3.5)	(7.9)	(4.1)	(1.1)	(4.2)	(4.4)	(19.0)	(3.5)	(9.3)
The southern region	3,714	6,773	3,964	3,714	1,830	154	1,706	2,344	9,447	1,103	6105
(ratio)	(3.2)	(5.9)	(6.5)	(6.1)	(3.1)	(0.3)	(3.2)	(4.1)	(15.9)	(1.7)	(9.7)
The eastern region	660	1,850	239	3,702	1,089	79	772	695	1,325	294	1,561
(ratio)	(4.1)	(12.2)	(1.9)	(35.3)	(9.9)	(0.7)	(7.8)	(5.8)	(11.4)	(2.5)	(14.2)
Subtotal	6,096	18,485	7,349	14,584	6,520	1,696	6,012	7,500	27,042	4,852	16,251
The ratio of agriculture in Taiwan	0.019	0.057	0.023	0.048	0.021	0.005	0.020	0.024	0.084	0.015	0.051
Income losses effect											
Northern	323	256	91	334	181	272	190	383	567	206	453
Middle	354	3,527	1,221	2,535	1,265	318	1,254	1,385	5,815	1,169	2,904
Southern	1,443	2,619	1,534	1,414	714	55	663	897	3,622	424	2,345
Eastern	331	890	113	1,788	517	39	384	325	630	140	750
Subtotal	2,451	7,292	2,959	6,071	2,677	684	2,491	2,990	10,634	1,939	6,452
Employment loss effect											
Northern	759	547	185	737	397	641	425	857	1,233	475	1,008
Middle	830	8,424	2,745	5,813	3,003	709	2,784	3,273	14,057	2,710	6,945
Southern	3,774	6,531	4,050	3,421	1,696	121	1,767	2,176	8,738	1,005	5,593
Eastern	715	1,976	252	3,963	1,159	85	834	735	1,401	312	1,664
Subtotal	6,078	17,478	7,232	13,934	6,255	1,556	5,810	7,041	25,429	4,502	15,210

Source: Simulation results of this study.

Note: 1. Income losses effect include labor return, operate revenue, depreciation and indirect tax.

2. Agricultural outputs of each county were quoted from the outputs of agricultural structure in Yearly Report of Taiwan's Agriculture

VI. Conclusion

This study explored the impacts of natural disasters in farm crops losses with supply side Input-Output analysis. We combined the data set witch included regional Input-Output table in Taiwan's counties, Regional Input-Output table and Yearly Report of Taiwan's Agriculture.

According to the empirical results, the whole product losses between 17 to 270.4 billions by the summation of direct losses of agriculture crops by disasters, indirect losses of product estimation by regional Input-Output model. Middle and southern areas were the worst and accounted over 80%, mainly due to these areas are the major agriculture regions. Secondly we compare GDP in present value every year and find economic growth declined 0.005%-0.084% by the losses effect of income, the ratio include direct and indirect effects.

In addition, we suggested that government study the feasibility of insurance policy. The reason due to the total losses (include direct and indirect losses) of natural disaster in agriculture in Taiwan increase the level of disaster losses every year, but the subsidy of natural disaster in agriculture less than 10 billion which government offers every year.

Reference

Alam, K. and J. Rolfe, 2006. "Economics of Plant Disease Outbreaks," *Agenda,* 13：133-146.

Charlotte, B. 2003. "Potential Approaches to the Development of Indicators for Measuring Risk from a Macroeconomic Perspective," Information and Indicators Program for Disaster Risk Management—Indicators for Disaster Risk Management , Inter-American Development Bank, Operation ATN/JF-7907-RG.

Charlotte, B. 2003. "Potential Approaches to the Development of Indicators for Measuring Risk from a Macroeconomic Perspective," Information and Indicators Program for Disaster Risk Management, Execution of Component II, Indicators for Disaster Risk Management , OPERATION ATN/JF-7907-RG, Inter-American Development Bank, IDEA.

From http://idea.manizales.unal.edu.co/.../DocDigitales/documentos/Charlotte%20Benson%20EM%20Barcelona%20Nov%202003.pdf

Chen, W. D.,1997. "Taiwan's Meteorological Disasters on Crop Damage Analysis," *Taiwan has limited land Finance Quarterly*, 1：1, 43-55.

Clower, T. L., 2005. "Economic Applications in Disaster Research, Mitigation, and Planning,"

From http://training.fema.gov/EMIWeb/edu/docs/Disciplines%20Disasters%20and%20EM%20Book%20-%20Chapter-Econ%20appli%20in%20disasters%20research.doc

Donaghy, K., Nazmiye, B. O. and H. Geoffrey, 2007. "Modeling Unexpected Events in Temporally Disaggregated Econometric Input-Output Models of Regional Economies," *Economic Systems Research,* 19, 125-145..

Fischer G., Mahendra S., and V. Harrij, (2002), Climate Change and Agricultural Vulnerability, Viena: International Institute for Applied Systems Analysis.

Gordon, P., Moore II, Richardson, H. W., Shinozuka, M. and S. Cho, 2004. "Earthquake Disaster Mitigation for Urban Transportation Systems：An Integrated Methodology that Builds on the Kobe and Northridge Experiences," From http://www-rcf.usc.edu/~pgordon/pdf/earthquake.pdf.

Gordon, P., Richardson, H. W., and B. Davis, 1998. "Transport-related Impacts of the Northridge Earthquake," *Journal of Transportation and Statistics,* 1：2, 21-36.

Huang, S.Y., 2004, *A Study on the Evaluation of Natural Disaster Losses in Taiwan : A Case Study of Typhoon and Mudflow Disaster in Taipei Metropolitan Area*, Master's thesis, Chinese Culture University Institute of Architecture and Urban Planning.

Jiang, F., Tatano, H., Kuzuha, Y., and T. Matsuura, 2005. "Economic Loss Estimation of Water Supply Shortage Based on Questionnaire Survey in Industrial Sectors,"Climate Change and Drought Impact Continuing Concern Regarding

Global Climate Change is Focusing on the Climate Forecast and Impact Assessment., Report of the National Research Institute for Earth Science and Disaster Prevention, No.68.

From http://www.bosai.go.jp/library/pub/report/PDF/68/68jiang.pdf

Lin, H. C. and T. M. Kao, 2006. “The Economic Impact from Agricultural Products Loss Caused by Natural Disasters and Regional Input-Output Analysis in Taiwan,” *Agricultural Economics Series,* 12：1, 105-138.

Lin, H. C. and T. M. Kao, 2008. An Assessment on the Regional Economic Effects of the Su-Hwa Highway Transportation Plan, *Taiwan's Economic Forecasts and Policy*, 38：2, 31-72.

Lu, Z. L., 2003. *Public Facilities, Flood Losses and Disaster Prevention Mechanisms Taiwan Study - Typhoon Nari in Taipei City as an Example,* Master's thesis, National Taiwan University, Institute of Agricultural Economics.

Miller, R. E. and P. D. Blair, 1985. *Input-Output Analysis: Foundations and Extensions,* Prentice Hall, Englewood Cliffs, New Jersy.

Okuyama, Y. 2007. “Economic Modeling for Disaster Impact Analysis Past Present and Future,” *Economic Systems Research,* 19, 115-124.

Rose, A., Benavides, J., Chang, S., Szczesniak, P., and D. Lim, 1997. “The Regional Economic Impact of an Earthquake：Direct and Indirect Effects of Electricity Lifeline Disruptions,” *Journal of Regional Science,* 37, 437-458.

Rose, A. and S. Liao, 2005. “Modeling Resilience to Disasters：Computable General Equilibrium Analysis of a Water Service Disruption,” *Journal of Regional Science,* 45：1, 75-112.

Tiebout, C. M. 1969. “An Empirical Regional Input-output Projection Model: The State of Washington 1980,” *Review of Economics and Statistics,* 51：3, 334-340.

Tsuchiya, S., Hirojazu, T. and O. Norio, 2007. “Economic Loss Assessment due to Railroad and Highway Disruptions,” *Economic Systems Research,* 19, 147-162.

Wu, Y. W., 2003. After the 921 *Earthquake Reconstruction Tourist Attractions in Central Taiwan's Economic Impact Analysis*, Master's thesis, National Taiwan University, Institute of Forestry Research Institute.

Yamano, N., Yoshio, K. and H. Yoshiharu, 2007. “Modeling the Regional Economic Loss of Natural Disasters the Search for Economic Hotspots,” *Economic Systems Research,* 19, 163-181.

Yang C. M., 1996. “Taiwan's Drought and Soil Water Effect on Rice Yield,” *Taiwan's Aagriculture*, 6：1, 76-88.

Output Based Allocation of Emissions Permits for Mitigating the leakage Issue for Japanese Economy*

Shiro Takeda[a]
Toshi Arimura[b]
Hanae Tamechika[c]
Carolyn Fischer[d]
Alan K. Fox[e]

Abstract

While the abatement of CO_2 emissions in the industrialized countries entails the reduction of energy-intensive production in those countries, it can increase the production of energy-intensive goods in countries without CO_2 regulations. This may lead to “carbon leakage”. If the Japanese government introduces a domestic emissions trading scheme (ETS) as the new ruling party claims, the leakage issue should be addressed in the design of ETS.

This paper examines the impacts of various allocation methods of emission permits in Japanese ETS on economy and GHG emissions using a multi-regional and multi-sector computable general equilibrium model. Specifically, we apply Fischer and Fox (2007) model to Japanese economy to deal with the leakage issue. We compare auction schemes, grandfathering schemes and output-based allocation (OBA) schemes. Further, we extend Fischer and Fox (2007) by examining the combination of auction and OBA. Though the auction scheme is found to be the best from the economic efficiency perspective, their leakage is high and the relocations of energy-incentive productions can be significant. Considering economic efficiency as well as the leakage issue, we find that the combined schemes of output-based allocation and auction are desirable.

JEL classification：C68,　D42

---

* We appreciate the financial supports from Center for Global Partnership, Japan Foundation and Mitsui & Co., Ltd. Environment Fund.
[a] Kanto Gakuen University/ Center for the Environment and Trade Research, Sophia University. Email: shiro.takeda@gmail.com
[b] Center for the Environment and Trade Research, Sophia University. Mailing address: 7-1, Kioicho, Chiyodaku, Tokyo, 102-8554, Japan. TEL:03-3238-3742, E-mail:t-arimu@sophia.ac.jp
[c] Sophia University/Osaka University
[d] Resources for the Future
[e] US International Trade Commission

Keywords : climate change, emissions trading, emissions permit allocations, output-based allocation, auction, grandfathering, international competitiveness, carbon leakage, CGE analysis.

Contents

1. Introduction

To deal with climate change issues, European Union has adopted a domestic emission trading scheme known as EU ETS (European Union Emission Trading Schemes). Other developed economies are also considering the adoption of domestic emissions-trading schemes (ETS). In adopting ETS, allocation methods of permits become an important issue. Already, numerous analyses have been conducted of ETS. Many studies find that allocation of permits through auctioning would be desirable in terms of both economic efficiency and equity.[1] However, it has been pointed out that auctioning permits would result in an excessive burden on energy-intensive industries. In particular, there is a possibility that energy-intensive industries competing with foreign competitors could lose their international competitive strengths, leading them to suffer massive reductions in production. In fact, such industries have demonstrated strong opposition to the adoption of emissions-trading schemes. Naturally, the political support of industry, including energy-intensive industries, is essential to adoption of emissions trading. For this reason, to ensure smooth adoption of emissions controls, there is a need to devise controls taking into consideration not just economic efficiency but also the burden on energy-intensive industries.

In addition, there are more than just political reasons for lessening the burden on energy-intensive industries. While emissions controls in developed nations can decrease the production of energy-intensive industries in such nations, they also could cause carbon leakage problems; production of energy-intensive industries increases in countries such as China and India where energy efficiency is lower and fewer reduction efforts are made. This shift of the production weakens the effects of carbon regulations in developed countries by increasing the emission in developing countries. If emission regulations are not adopted in some regions, major contractions in energy-intensive industries in regions facing regulations could result simply in large-scale leakage. In light of the potential for such leakage as well, policy makers need caution to place an excessive burden on energy-intensive industries.

The free allocation of emissions permits, instead of auctioning, has been proposed as a response to the issue of an excessive burden on energy-intensive industries. In fact, EU ETS employs a grandfathering method in Phase II (from 2008-2012).[2] In addition, recently, another type of free allocation method, output-based allocation (OBA) has attracted attention. In OBA method, emission permits are distributed gratis based on industrial output. For example, in the United States proposals such as the Lieberman-Warner and Waxman-Markey bills have proposed this OBA method to

---

[1] In this paper, "economic efficiency" is defined as efficiency measured from the perspectives of GDP and welfare.

[2] However, it must be noted that the targets of reductions in the first (2005–2007) and second (2008–2012) phases of the EU ETS are limited to sectors such as manufacturing and the energy-conversion sector.

protect domestic industries that compete in international markets, with the objective of preventing leakage. This method would distribute, free of charge, certain amounts of emissions allowances to firms involved in international competition.

In response to the growing interest in the OBA method in the U.S., Fischer and Fox (2007) employ a computable general equilibrium (CGE) model in quantitative analysis of the three methods of auctioning, grandfathering, and the OBA method in the United States. Their analysis suggests that the OBA method is effective to some degree in both preventing concentration of the burden on energy-intensive industries and restraining leakage. There is a high likelihood that in the future full-fledged emissions trading will be adopted in Japan as well. For this reason, quantitative economic analysis of different allocation methods of permits is likely to provide very useful information for policy decision-making. Based on this awareness of the issues, in this study, we apply the Fischer and Fox model to Japan for the comparison of various allocation methods of permits.

Specifically, we construct the following model. First, it is a multi-regional and multi-sector static CGE model. For data on production, imports and exports, and other activities we will use the GTAP 7 database, with 2004 as the base year. The model has 14 regions and 27 sectors. We assume that each country and region consists of three economic agents: households, firms and government, and that each of these behaves optimally. To analyze energy production activities in detail, we have designated two types of production functions compliant with the GTAP-EG model: a fossil-fuel production function and a non-fossil-fuel production function. We also assume that household utility depends on consumption and leisure, i.e., households choose the supply of labor endogenously. Taxes on labor generate distortion in the labor market. Consequently, taxation on labor results in an insufficient supply of labor under the benchmark equilibrium. These assumptions are employed to consider cases in which revenues from emissions permits are used to reduce taxation on labor.

For regulations on emissions, our analysis assumes a cap-and-trade scheme restricting total emissions. In addition, we assume that emissions controls are adopted by Japan, the U.S., and the 27 EU member states simultaneously, reducing emissions in these regions by 30%, 20%, and 16%, respectively, from 2004 levels. We also assume that no scheme for international emissions trading is adopted, with emissions permits traded only internally within each country or region. In addition, since the primary aim of this study is to analyze emissions trading in Japan, we assume that the U.S. and the EU-27 countries allocate quotas using a method of auctioning at all times, with only Japan changing allocation methods.

To begin with, similarly to Fischer and Fox, we compare the following four allocation methods: auctioning (AUC), grandfathering (GF), an OBA method in which emissions permits are allocated among industries based on their shares of past carbon-dioxide emissions (OBA-HE), and an OBA method in which emissions permits are allocated among industries based on their shares of past value added (OBA-VA). The three methods GF, OBA-HE, and OBA-VA each allocate permits freely. As opposed to the GF method, in which permits are allocated independently of firm behavior, permits are given to firms in a manner linked to their production outputs under the two OBA. Since this allocation method is similar in effect to subsidizing production, the OBA method has the following effects: (1) it keeps down increases in prices of production due to the addition of emissions controls, and (2) in industries to which large amounts of emissions permits are allocated gratis, it makes it more difficult to substitute with non-energy inputs. The former effect in particular has the following two positive impacts: reducing negative effects through the tax-interaction effects (in which real wages are lowered due to rising prices of production and labor supply, which already is insufficient, is decreased further) of adoption of emissions controls[3] and restraining leakage.

Of the four methods above, auction (the AUC) and free allocation (i.e., the GF and the two OBA methods) are handled separately. In actual discussion of emissions controls, however, a combination of auction and free allocation methods have been proposed. That is, some industries receive permits gratis and others obtain permits through auctioning. For example, while plans call for the EU ETS to shift to an auctioning method in principle in the future, the policy also calls for continuing free allocation on an exceptional basis for industries facing overseas competitors (such as the steel industry).[4] Such a hybrid allocation method is under consideration in Japan as well. In light of such circumstances, we also analyze the method of allocation free of charge to some industries only. Specifically, we analyze the scenario of free allocation through the OBA-HE method to some industries only and auctioning (the AUC) to other industries. As the industries with gratis allocation, we consider three cases: seven trade-exposed energy intensive (TEEI) sectors, electricity and three transport sectors (Scenario AO-A), only TEEI sectors and transport sectors (Scenario AO-B) and only TEEI sectors (Scenario AO-C). These sectors with gratis allocation are selected according to criteria used in the U.S. Clean Energy and Security Act of 2009 (for details, see Sugino, Arimura, and Morgenstern, 2009).

Whichever method is employed, emissions permits for household carbon-dioxide emissions would be allocated through auctioning. We also assume that the government would adjust labor taxes to keep government expenditures at a fixed level. For example, while large amounts of revenues from emissions permits are received by the government under the AUC method, the remainder after financing a certain level of government expenditure is used to reduce labor taxes. This revenue-recycling effect under AUC results in improvements of the distortion in labor markets.

While Fischer and Fox (2007) employ largely the same framework, the main differences between their study and this study are as follows. First, while Fischer and Fox use the U.S. data for

---

[3] See Bovenberg and Goulder (2002) for a detailed discussion of the tax-interaction effect (and the revenue-recycling effect).

[4] Planned to begin with the third phase, starting in 2013.

endogenizing labor-supply, this study employs Japanese data. Second, while Fischer and Fox use GTAP6 data with 2001 as the base year, we use GTAP7 data with 2004 as the base year. Third, this study also analyzes a hybrid allocation method combining the auction and OBA methods. Finally, while the Fischer and Fox analysis assumes no regulation in regions other than the U.S., our study assumes adoption of emissions controls in the U.S. and the EU-27 countries at the same time as in Japan. Under this framework, we analyze how allocation methods for emission permits change the impacts of the emissions controls on welfare, GDP, prices of emissions permits, leakage, and production in each sector, carbon-dioxide emissions, employment, trade, and other conditions.

In addition to Fischer and Fox, a large number of studies have conducted analyses of emissions trading from the perspective of initial allocation methods for emissions permits. This remains true even when looking only at studies employing CGE models. First, Parry et al. (1999) employed a static CGE model to compare emissions trading using auctioning and free allocation under conditions of taxation leading to imbalances in the United States.[5] Again focusing on the U.S., Goulder et al. (1999) compare various controls on carbon-dioxide emissions, including emissions trading. Employing a forward-looking dynamic CGE model, Jensen and Rasmussen (2000) compare the three allocation methods of auctioning, grandfathering, and an OBA method based on market share in emissions trading in Denmark. Böhringer and Lange (2005) analyze the effects of emissions trading in the EU (mainly Germany), under the three methods of auctioning, the OBA method, and allocation free of charge based on emissions volume (i.e., share of emissions). Finally, Dissou (2006) employs a forward-looking dynamic CGE model to analyze emissions trading in Canada under the three allocation methods of auctioning, grandfathering, and the OBA method.

While these analyses differ in various aspects of the models employed (i.e., production structure, whether they cover a single nation or multiple regions, and whether they are dynamic or static), allocation methods, and assumptions concerning emissions controls (e.g., whether or not international emissions trading is permitted, whether factors other than emissions trading are included in the subject of comparison), making it possible to consider emissions controls from a diverse range of perspectives, since in each (including Fischer and Fox) the subject of analysis is Europe or North America, their analysis is not centered on Japan. In light of this situation, this paper can provide useful information for emissions controls in Japan, since its primary subject of analysis is emission trading in Japan and it establishes parameters, data, and scenarios suited to this purpose.

Important results of our analysis can be summarized as follows. First, our analysis shows that when allocation methods are compared from the standpoint of economic efficiency (i.e., effects on welfare and GDP), the most preferable method is the AUC method, followed by the OBA-VA and

---

[5] In fact, they compared a tax-revenue-neutral carbon tax (reducing tax on labor) with emissions trading through allocation free of charge. However, the former policy had the policy equivalent to the revenue-neutral auction-based emissions trading (reducing tax on labor).

AO, and then the OBA-HE and, lastly, the GF. On the other hand, the results show that the OBA-HE and AO methods are superior in controlling carbon leakage as low as possible. Furthermore, from the perspective of the reduction of the burden on domestic energy-intensive industries, AO and OBA-HE are desirable. Comprehensively taking the above results into consideration, it can be said that the AUC method is the best allocation method if top priority is given to economic efficiency. The AUC method, however, has considerable negative effects in the area of overseas leakage and on domestic energy-intensive industries. When also giving consideration to restraining leakage and avoiding excessive burdens on domestic energy-intensive industries, instead of just economic efficiency, the AO (in particular, AO-C) method can be said to be a well-balanced allocation method, although it is somewhat less efficient. In addition, our study also shows that the AO (or OBA-HE) method shifts the burden of emissions reductions to the household sector and that it could protect energy-intensive industries excessively.

2. The Model

We construct a static CGE model with 14 regions and 27 sectors listed in Table 1. The structure of the model is similar to that of Fischer and Fox (2007) and GTAP-EG (Rutherford and Paltsev 2000). In each region, there are three types of agents; representative household, government and firms. A household supplies capital, labor, land and natural resources and then allocates his factor income to purchase of goods and investment (savings). The utility of the household depends on consumption and leisure, and he determines consumption and leisure so as to maximize the utility subject to a budget constraint. We assume that capital and labor are mobile within a region, and that land and natural resources are sector-specific factors.

Next, the government collects tax revenue from output taxes, intermediate demand taxes, factor taxes, final demand taxes, import tariffs and export taxes. We assume that tax rates are constant except for tax rate on wage income. The tax rate on wage income is assumed to be determined endogenously so that the government expenditure is held constant. In addition to tax revenue, the government collects permit revenue, which is assumed to finance reduction in tax on wage income. Finally firms produce goods with constant returns to scale technology to maximize profits using primary factors and intermediate inputs. To explain bilateral cross-hauling in goods trade, we use the so-called Armington assumption: goods produced in different regions are qualitatively distinct (Armington, 1969).

We assume two types of production function; the fossil-fuel production function and the non-fossil fuel production function. Fossil fuel production activities include extraction of coal (COL), crude oil (OIL), and natural gas (GAS). Production has the structure shown in Figure 1: Production function of fossil fuel sectors. Fossil fuel production is basically the same with GTAP-EG model

(Rutherford and Paltsev, 2000). Fossil fuel output is produced as a constant elasticity of substitution (CES) aggregate of natural resources and non-natural resources input composite. The non-natural resources input is a Leontief composite of capital, labor and intermediate inputs.

Non-fossil fuel production (including electricity) has the structure in Figure 2. Non-fossil fuel production is also basically the same with GTAP-EG model. Output is produced with Leontief aggregation of non-energy goods and an energy-primary factor composite. The energy-primary factor composite is a CES function of energy composite and primary factor composite. The primary factor composite is a CES aggregation of primary factors. The energy composite is a CES aggregation of electricity (ELY) and non-electric energy input composite. The non-electric energy is a CES aggregation of coal (COL) and liquid energy composites and the liquid energy composite is a CES aggregation of petroleum and coal products (P_C) and gas (GAS). In addition, with respect to the petroleum and coal products sector, we assume that crude oil enters into the production function at the top-level Leontief nest because most of crude oil is used as feedstock. Similarly, for the chemical products sector (CHM), we divide its energy use into feedstock requirements, which are treated as non-energy intermediate inputs, and the remainder. For this, we use the feedstock ratio data of Lee (2009).

The utility function for the representative household is a nested CES function shown in Figure 3: Utility function.. We assume that the representative household derives utility from leisure and aggregate consumption. Aggregate consumption is a CES aggregation of a non-energy composite and energy composite. The non-energy composite is a Cobb-Douglas aggregate of non-energy goods, and the energy composite is a Cobb-Douglas aggregate of electricity, petroleum and coal products, gas, and coal.

3. Data.

For the benchmark data, we employ the GTAP 7 database with 2004 as the base year. We aggregated the GTAP 7 data into 14 regions and 27 sectors listed in Table 1. For CO_2 emissions data, we basically use the data included in GTAP7 data, but CO_2 emissions of Japanese iron and steel sector (I_S) provided by GTAP 7 are far less than the actual value (3EID, 2009). Because the iron and steel sector is of great importance in the analysis of emissions regulation, we correct the data according to the data provided by 3EID. For elasticity parameters in production functions, we basically use the values of Fischer and Fox (2007) and GTAP data and for Armington elasticity parameters, we use GTAP values.

One of the key parameters in our model is the elasticity of substitution between leisure and consumption in the utility function. For the parameter of Japan, we use the value of 0.73. This is the value estimated by Hatano and Yamada (2007) from leisure and labor data in Japan. In addition, we derive the benchmark labor tax rate and leisure time for Japan from labor and tax data of Japan (ESRI, 2007, MFPRI, 2008 and MHLW, 2008).[6]

To derive the leisure-consumption elasticity and the leisure time in other regions, we use the same approach with Fischer and Fox (2007). They calibrate the elasticity of substitution between leisure and consumption and that between the hours of leisure and work, given economic estimates of compensated and uncompensated wage elasticity of labor supply. Following Ballard (1999), the values of compensated and uncompensated wage elasticity of labor supply are set at 0.1 and 0.3, respectively.

4. Policy Scenarios

The abatement of CO_2 emissions induces the decline in the economic activity levels or welfare losses for the abating countries. We need to design the domestic emission trading scheme to ease these negative impacts. In Japan, there have been discussions about the domestic trading scheme, in particular, about allocation methods of permits.

We assume that emissions controls are adopted by Japan, the U.S., and the 27 EU member states simultaneously, reducing emissions in these regions by 30%, 20%, and 16%, respectively, from 2004 levels. Our main purpose is to analyze the impacts of emission trading in Japan but we assume emission regulations in three regions because the unilateral restraint on CO_2 in Japan leads to extremely high permit price. Our analysis assumes a cap-and-trade scheme to restrict the emissions from the abating regions. We also assume that no scheme for international emissions trading is adopted, with emissions permits traded only internally within each country or region. In addition, since the primary aim of this study is to analyze emissions trading in Japan, we assume that the U.S. and the EU-27 countries allocate permits using a method of auctioning, with only Japan changing allocation methods. Across all policy scenarios we assume that representative households always obtain permits through the auction.

In order to analyze the effects of different Japanese allocation methods, we set up seven scenarios. Table 2 briefly summarizes the key features of seven scenarios. Scenario AUC is the auction scheme in which all permits are allocated by the auction. GF is the grandfathering allocation. With GF, permits are allocated gratis to industries independently of firm behavior. OBA is the output-based allocation scheme. In OBA scheme, allocation of permits is determined by the two stages: intra-industry allocation and inter-industry allocation. Intra-industry allocation is determined in proportion to firms' output. On the other hand, inter-industry allocation is determined by the following two rules. First, permits are allocated among industries according to the historical value

[6] The estimated share of leisure time in total available time is 58.5% and the estimated labor tax rate is 50% in the net term.

added shares (OBA-VA). Second, permits are allocated according to the historical emissions shares (OBA-HE). Moreover, we consider the combination of auction and OBA-HE schemes (AO). Scenario AO is divided into three cases according to which industries obtain free allocation. In Scenario AO-A, trade-exposed energy-intensive (TEEI) sectors, electricity sector and transport sectors are given free allocation. In Scenario AO-B, only TEEI sectors and transport sectors are given free allocation. In Scenario AO-C, only TEEI sectors obtain free allocation. The details of allocation schemes are presented in the next section.

Under this framework, we analyze how allocation methods for emission permits change the impacts of the emissions controls on permit price, welfare, GDP, consumption, employment, carbon leakage, and production in each sector, CO_2 emissions, employment, trade, and other conditions.

4.1. Permit Allocation

In the previous studies, there are some differences in the definitions of grandfathering and OBA. For example, some studies identify grandfathering with gratis allocation while other define grandfathering is one of gratis allocation methods. In order to avoid confusion, we explain the details of allocation methods in the following.

4.2. Auction (AUC)

We consider a representative firm in sector *i*. For simplicity, we ignore the permit revenue from a representative household for the time being. As firms produce goods under constant returns to scale technology, we can define the unit cost function of production $c_i(w, pco2)$ where w is the input price and $pco2$ is the permit price. Let y_i be the output of firm and p_i be the market price for the good produced. Then the firm's profit is given by

$$\pi_i = (p_i - c_i)\, y_i.$$

Since the firm does not receive gratis permits, the profit does not include the value of gratis permits. Using *Shephard's lemma*, $(\partial c_i / \partial pco2)\, y_i$ is the demand for permits in sector *i*, which is equal to the permits purchased E_i. By the profit maximization condition, we obtain $p_i - c_i = 0$, which means that the profit is equal to zero ($\pi_i = 0$). The government collects permit revenue, $pco2 \times \Sigma i E_i$, and uses it to to lower tax on labor income.

4.3. Grandfathering (GF)

Let A_i be the amount of free permits allocated to sector *i*. Then the profit in the gratis allocation schemes is given by

$$\pi_i = (p_i - c_i)\, y_i. + pco2 \times A_i. \qquad (1)$$

In the gratis allocation schemes, the value of free permits is added to the profit. The difference among various gratis allocation schemes lies in how to treat A_i. To model the grandfathering scheme, we use the approach used in Fischer and Fox (2007), Jensen and Rasmussen (2000), Parry et al. (1999), Goulder et al. (1999), Fullerton and Metcalf (2001) and Dissou (2006). In their approach, the grandfathering scheme means that permits are given to firms in a lump-sum fashion independently of firm behavior. This is represented by the assumption that individual firms regard A_i as constant. From this assumption, the FOC for the profit maximization is $p_i - c_i = 0$, which is the same as the auction scheme. As in the auction scheme, the demand for permits is given by $(\partial c_i / \partial pco2)y_i$. But the amount of permits purchased is $E_i = (\partial c_i / \partial pco2)y_i - A_i$ (the negative value of E_i means that the firm sells permits to other firms). The government does not collect permit revenue because he allocates all permits for free. $p_i - c_i = 0$ implies that the firm obtains the excess profit:

$$\pi_i = pco2 \times A_i.$$

We assume that this excess profit is transferred to the household in a lump-sum fashion. The same profit maximization condition with the auction scheme means that the condition for determining firm behavior is the same in AUC and GF.

4.4. Output-based allocation (OBA: OBA-HE, OBA-VA)

Since output-based allocation (OBA) is the gratis allocation as GF, a firm's profit is given by Eq. (1). What is different from GF is that intra-industry allocation of permits is conducted according to the level of output. This assumption is represented by the following formula: $A_i = a_i\, y_i$,where a_i is the amount of free permits per output.[7] Therefore, the firm profit becomes:

$$\pi_i = (p_i - c_i)\, y_i + pco2 \times a_i\, y_i.$$

With output-based allocation, the allocation to individual firms in a sector is updated based on their output shares within the sector. The more the firm produces, the more free permits the firm receives, and this results in positive effects on profit. This dependence of free permits on firms' behaviors (output) is the main characteristics of OBA. The profit maximization condition is given by

$$p_i + pco2 \times a_i - c_i = 0.$$

Even if c_i increases by CO_2 emissions control, the rise in goods price is restrained by the existence of $pco2 \times a_i$. Hence, the rise in goods price in OBA scheme is lower than in auction and grandfathering. This weakens the tax-interaction effect induced by emissions control. The number of permits to purchase is $E_i = (\partial c_i / \partial pco2)y_i - A_i$. Although the allocation of permits within a sector is determined by output shares, the allocation of permits among sectors is determined by different

[7] a_i is regarded as constant by individual firms, but it is adjusted so that $A_i = a_i y_i$ holds for exogenous A_i.

rules[8]. We consider the following two rules for allocation among sectors: historical value added share (OBA-VA) and historical emissions share (OBA-HE).

4.5. The combination of auction and output-based allocation (AO: AO-A, AO-B, AO-C)

AO-A, AO-B, and AO-C is the allocation methods in which OBA-HE is applied to some industries and auction (AUC) to other industries. Firm behavior is the combination of auction and output-based allocation. With AO-A, free permits are distributed to 11 energy-intensive sectors as a whole (electricity, TEEI sectors and transport sectors).[9] With AO-B, free permits are distributed to TEEI sectors and transport sectors. Finally, with AO-C, free permits are distributed only to TEEI sectors. The amount of permits freely allocated decreases from AO-A to AO-C. The reason why we consider three cases is that there is not yet consensus on which sectors will be assigned gratis allocations. In the remainder of the paper, Scenario AO means AO-A to AO-C as a whole.

4.6. Remarks

Across all policy scenarios, the representative household always obtains permits by auction. Moreover, it is assumed that permits are allocated to fossil fuel sectors (OIL, GAS, COL) by auction even in GF and OBA, Therefore, the government obtains permits revenue even in the gratis allocation schemes.

4.7. The volume of gratis permit

As mentioned above, permits are allocated gratis to firms under GF, OBA and AO. Allocations within sectors in OBA are determined according to output level. On the other hand, allocations at the sector level are determined as follows. Let CO2F0 be the total CO_2 emissions from all sectors and φ be the CO2 reduction rate of Japan. The total amount of free permits allocated to total sectors is CO2F0×(1-φ). That is, the amount of gratis allocation to total sectors is equivalent to the reduced benchmark CO_2 emissions with the reduction rate. Total emissions quotas in Japan under CO_2 emissions control amount to 833.2 MtCO_2 (total CO_2 emissions in benchmark × (1-0.3) and 720.7 MtCO_2 of permits are allocated to sectors for free. Therefore, 86% of total emissions quotas are distributed gratis to sectors and the rest of permits is auctioned.

With OBA, the sector allocations are based on two rules: historical CO_2 emissions shares and

---

8 Some studies assume that the permits allocations among sectors are based on OBA (their output shares) as well. See Böhringer and Lange (2005).

9 Trade-exposed energy-intensive sectors include FSH, OMN, SGR, PPP, CRP, NMM and I_S and transport sectors include OTP, WTP and ATP.

historical value-added shares. In the scenario OBA-HE, total emissions quotas in sectors, CO2F0×(1-φ), are allocated gratis to sectors in proportion to their benchmark CO_2 emissions. In the scenario OBA-VA, total emissions quotas in sectors equivalent are allocated gratis to each sector according to its benchmark value-added share. Table 3 reports the sector allocations for OBA.

With AO, only energy-intensive sectors (or the part of them) receive free permits. Let CO2FE0 be the total CO_2 emissions in energy-intensive sectors. The total amount of free permits allocated to energy-intensive sectors is CO2FE0×(1-φ), which is distributed gratis to these sectors in proportion to their benchmark CO_2 emissions. Total amount of gratis allocation for AO-A, AO-B, and AO-C is 610.2 MtCO_2 (73% of total emissions quotas), 332.3 MtCO_2 (40%), 191.2 MtCO_2 (23%) respectively.

With OBA-VA, the amount of gratis allocation in services and non-energy-intensive sectors, which have the large shares in the economy, is large and that in energy-intensive sectors is small instead. Therefore, OBA-VA is not favorable to energy-intensive sectors. On the other hand, with OBA-HE, the amount of gratis allocation in energy-intensive sectors, in particular, ELY, OTP, CHM and I_S is larger than that in other sectors. It follows that OBA-HE favors energy-intensive sectors. With AO, only energy-intensive sectors (or the part of them) receive permits for free and other sectors have to buy their permits through the auction. Compared to OBA-HE, AO is the more favorable allocation method for energy-intensive sectors because non-energy-intensive sectors do not receive any permits for free and must buy them at the auction. Table 3 does not report allocations in GF because sector allocation has no impacts on results in GF.[10]

5. Simulation results

5.1. Macroeconomic impacts and economic efficiency

We now explore the simulation results in seven different allocation methods. We begin with the macroeconomic impacts with all scenarios. In the following, the benchmark equilibrium with no abatement action is called business-as-Usual (BaU). Table 4 summarizes the results across all scenarios. A permit price (US dollars per metric ton of CO_2) is the highest in OBA-HE, followed by AO-A, AO-B, AO-C, OBA-VA, AUC, and GF in decreasing order. Permit prices range from a high of \$133.7 in the scenario OBA-HE to a low of \$93.7 in the scenario GF, which shows that permit prices differ across allocation methods by around \$40. The reason for the highest permit price (the marginal abatement cost) with OBA-HE is that it favors carbon-intensive sectors. When carbon-intensive sectors are favored, other industrial sectors or the household must reduce their

[10] This is because the sectoral allocation does not affect firm behavior and because rents from gratis allocation are transferred to to the representative household in a lump-sum fashion.

emissions more and it requires the high permit price. The permit price of AO becomes closer to that of AUC with the share of auctioned permits increases from AO-A to AO-B, and to AO-C. Conversely, the permit price of AO becomes closer to that of OBA-HE with the share of gratis permits increases. While the permit price in AO-A is the almost the same as OBA-HE, the permit price in AO-B and AO-C is very close to AUC. This suggests that it is of great importance whether electricity sector receives gratis allocation or not.

The impacts on welfare are negative in all allocation methods. The negative welfare effects are the lowest in AUC, followed by AO-C, AO-B, OBA-VA, AO-A, OBA-HE, and GF. The negative effect is the smallest in the scenario AUC (-0.25%) and the greatest in the scenario GF (-0.60%). Welfare effects in AO-C and in AO-B are -0.31% and -0.36% respectively, which is close to the welfare effect in AUC, due to the large amount of permits auctioned. On the other hand, welfare effect in the scenario AO-A that allocates gratis permits to electricity sector is -0.47%, which is close to the value in the scenario OBA-HE (-0.49%). This also indicates that the gratis allocation to electricity sector makes the large difference in results.

On the other hand, GDP loss is the smallest in AUC, followed by AO-C, AO-B, OBA-VA, AO-A, OBA-HE, and GF in increasing order. The smallest GDP loss is -0.06% in the scenario AUC while the largest is -1.10% in the scenario GF. The ordering of allocation methods by GDP loss is the same as that by welfare loss but the dispersion of GDP losses is larger. As with welfare loss, GDP losses in AO-C and AO-B are close to that in AUC and GDP loss in the scenario AO-A is close to that in the scenario OBA-HE. Taking the above results into consideration, we can conclude that in terms of economic efficiency, AUC is the most desirable allocation method.

Since welfare and GDP depend on consumption, let us examine the change in consumption. The negative impacts on consumption are the smallest in AUC, followed by AO-C, AO-B, OBA-VA, AO-A, OBA-HE and GF. This ordering is the same as that of welfare and GDP effects. This shows that the effects on welfare and GDP are closely linked to that on consumption.

The scenario AUC yields an increase in consumption. In the scenarios AO-C and AO-B, the decreases in consumption are small. The reason for the positive or small negative changes in consumption is the revenue-recycling effect. Since permit revenue is used to lower the labor tax, AUC that generates the large amount of permit revenue increases the real wage for the representative household. As a result, labor supply, which is at insufficient level in BaU, increases[11]. This increase in labor supply increases labor income, and thereby consumption increases. In the scenario AUC, the government collects permit revenue of roughly 825 billion US$, and the revenue-recycling effect lowers the labor tax rate by six percentage points (from 50% in BaU to 44%). This leads to the rise in the real wage and employment by 1.00% and 0.89%, respectively, which results in increases in

[11] In the scenario BaU, welfare is improved by a decrease in tax on labor income. Detailed simulation result is available upon request.

labor income and total income by 1.90% and by 0.10%, respectively. As a consequence, consumption increases by 0.10%. Permit revenue for AO-C and for AO-B is smaller than that for AUC because the amount of permits auctioned is smaller (permit revenue is roughly 678 billion US$ for AO-C and 538 billion US$ AO-B). Nevertheless, the revenue recycling effect reduces the decrease in consumption under scenario AO-C and AO-B (-0.19% for AO-C and -0.36% for AO-B respectively).

On the other hand, the large decrease in consumption in Scenario GF is attributed to the following two reasons. First, because permits are allocated to sectors for free, the revenue-recycling effect becomes small in GF. Second, the negative impacts of the tax-interaction effects become more apparent in GF than in others. Compared to OBA which has the effect similar to production subsidy, the output price increases more in GF. This rise in output price results in lower real wage and thereby the decrease in labor supply which is already at insufficient level (this effect is called the tax-interaction effect). The reason for the large decrease in consumption in GF is the small revenue-recycling effect and the large tax-interaction effect.

With OBA-HE that allocates gratis permits to sectors, the revenue-recycling effect becomes small as in GF. However, the increase in output price under OBA-HE is small compared to that under GF, because OBA allocates gratis permit to firms in proportion to their output, which is equivalent to production subsidies. As a result, the tax-interaction effect is smaller in OBA-HE than in GF. Hence, the decrease in consumption is smaller in OBA-HE than in GF.

OBA-VA scheme is inferior to AO-B and AO-C but superior to OBA-HE. The reason why OBA-VA is worse than AO-B and AO-C is that it has only small permit revenue and thus the revenue-recycling effect becomes small. On the other hand, the reason why OBA-VA is superior to OBA-HE is that the former allocation method based on VA shares has uniform effects on all sectors, whereas the latter favors energy-intensive sectors.

5.2. Carbon leakage

5.2.1. Total leakage

This section examines how the carbon leakage rate differs among our seven allocation methods. The carbon leakage rate is defined as the ratio of total additional CO_2 emissions in non-abating regions to total CO_2 emissions abated by abating regions[12]. Table 4 shows that the leakage is the

[12] For example, when a decrease in CO_2 emissions by abating-countries of 100 million tons will lead to the increase in CO_2 emissions by the non-abating countries of 30 million tons, the leakage rate is 30%. Let n be the non-abating countries and m be the abating countries, the formula for the carbon leakage rate is:

smallest in OBA-HE, followed by AO-A, AO-B, AO-C, GF, AUC, and OBA-VA. Except for GF and OBA-VA, the leakage rate decreases with the number of sectors with gratis permits. The leakage rates range from a low of 15.30 % to a high of 16.10%, and this result indicates that the leakage rates do not significantly depend on allocation methods. There are possible two reasons for it. First, this leakage rate is derived from abatement by three abating regions (Japan, US, and EU27) and do not represent the leakage only from Japan. Second, only Japan changes allocation methods; the U.S. and EU27 allocate quotas using auctioning at all time. Since the above leakage rate includes the leakage from US and EU27, it is difficult to evaluate the leakage from Japan. To extract the effects by Japan, we report the leakage rate in the case of the unilateral reduction by Japan. The qualitative results are the same as in the case of the multilateral reduction, but the leakage rates become far larger. In addition, the difference in the leakage rates is expanded (from a low of 32.42 % to a high of 36.92%). These results show that the choice of allocation scheme in Japan can make the large impact on the leakage from Japan. In terms of economic efficiency, AUC is the most desirable allocation method. However, the above results show that OBA-HE and AO are more desirable than AUC in terms of the leakage issue.

5.2.2. Leakage by Sector

This section examines the carbon leakage by sectors in the non-abating regions[13]. Table 5 compares how CO_2 emissions increase by sector in non-abating regions for seven allocation methods. It reveals that the leakage in energy-intensive sectors is large in all allocation methods. As discussed in Section 5.3.1, total leakage is not so different across allocation methods, but the leakage in TEEI sectors, in particular, iron-steel sector (I_S), differs substantially across allocation methods, which ranges from a low of 19.4 MtCO_2 to a high of 30 MtCO_2. This shows that iron-steel sector plays the important role in determining the carbon leakage.

5.2.3. Leakage by Region

Table 6 shows carbon leakage in non-abating regions for each of the allocation scenarios. In all scenarios, there is the large amount of leakage to the Former Soviet Union (FSU) and China (CHN). However, since the change in allocation schemes makes only small impacts on the carbon leakage to

---

$$\text{Carbon leakage rate } (\%) = \frac{\sum_n \left(CARB_{1,n} - CARB_{0,n}\right)}{\sum_m \left(CARB_{0,m} - CARB_{1,m}\right)} \times 100 ,$$

where $CARB_0$ is the level CO_2 emissions in BaU and $CARB_1$ denotes CO_2 emissions in a counterfactual scenario.

[13] Non-abating regions include eleven countries or regions other than Japan, the U.S. and the EU 27 countries.

FSU, most of the carbon leakage to FSU can be attributed to the leakage from USA and EU27. On the other hand, the change in allocation schemes makes the relatively large impacts on the leakage to CHN. It indicates that China is the main destination of the leakage from Japan.

5.3. The Effects of CO_2 Emission Abatement on Each Sector

The main reason for gratis allocation methods is to lessen the burden on energy-intensive industries. We now turn to the effects of allocation methods on various sectors. Although there are many possible indicators which represent the sectoral effect of CO_2 emissions abatement, we analyze effects on the sectoral CO_2 emissions, output and net export.

5.3.1. CO_2 Emissions in Each Sector

Table 7 reports the percentage change in CO_2 emissions from sectors and the household. First, we can see that CO_2 emissions decrease to the large extent in energy-intensive sectors, in particular, electricity and TEEI sectors. Second, in electricity sector, the decreases in CO_2 emissions in OBA-HE and AO-A are smaller by roughly 10MtCO_2 than in AUC and GF. This implies that OBA reduces the abatement of the electricity sectors. However, with AO-B and AO-C which give no gratis allocation to electricity sector, the CO_2 abatement of electricity sector increases relative to AUC. Third, in trade-exposed energy-intensive sectors, the reduction in AUC, GF and OBA-VA is roughly 92MtCO_2 while that in OBA-HE and AO is roughly 85MtCO_2. Finally, the reduction rates in the household sector (HH) under AO-A and OBA-HE are significantly high compared to other allocation methods. Since AO-A and OBA-HE allocates the large amount of gratis permits to energy-intensive sectors, these two allocation methods give favorable treatment to energy-intensive sectors. This requires the large abatement in other sectors and the household, which results in the higher permit price. In fact, we have already seen that the permit prices for AO-A and OBA-HE are much higher than those for other allocation methods. This means that AO-A and OBA-HE methods shift the burden of emissions reductions from energy-intensive sectors to the household.

5.3.2. Outputs

Table 8 summarizes percentage changes in output from BaU. Output in all sectors tends to decrease, and then, the rate of the decrease in output differs by allocation methods. With GF, the decrease rates in output for almost all sectors are the highest relative to other allocation methods. With AUC, the rates of decrease in output for TEEI sectors are the third largest compared to other allocation methods, and the rates of the decrease in output for non-energy-intensive (NEINT) sectors are smaller relative to other methods. The rates of the decrease in output for OBA-VA are generally higher than those for AUC on the whole, but OBA-VA and AUC have the similar impacts. On the other hand, OBA-HE and AO have the quite different impacts from AUC. While, with OBA-HE and AO, the rates of decrease in output for energy-intensive sectors are lower compared to AUC, the rate of decrease in output for other sectors are higher instead. As predicted, negative effects on energy-intensive sectors are generally small under OBA-HE and AO. However, AO-B and AO-C, which give no gratis permits to electricity or transport sectors, have the negative impacts on electricity and transport sectors as in AUC.

The above results show that OBA-HE and AO tend to reduce the negative impacts on energy-intensive sectors. It should be pointed out that, however, with OBA-HE and AO-A, the rates of the decrease in output for TEEI sectors are smaller than those for non-energy-intensive sectors. This results contrast to AUC's. This means that OBA-HE and AO-A favor TEEI sectors excessively, rather than reducing the burdens on them. If we try to realize the well-balanced distribution of burdens to all sectors, OBA-HE and AO-A are too favorable to (trade-exposed) energy-intensive sectors.

5.3.3. Net Exports

Table 9 presents the change in net exports (Billions of US$). Since Japan does not trade electricity, its numerical value is not reported in Table 9. The total net exports decrease in all scenarios and it size is similar across allocation schemes. But the impacts on net exports of individual sectors are quite different across allocation schemes. Net exports of TEEI sectors decrease significantly in AUC, GF and OBA-VA but slightly in OBA-HE and AO. Conversely, net exports of non-energy intensive sectors decrease significantly in OBA-HE and AO but slightly in AUC, GF and OBA-VA. It shows that the volume of net exports in individual sectors depends crucially on allocation methods.

5.3.4. Summary of the Sectoral Effects

We analyzed how the effects of CO_2 emissions abatement differ by the allocation methods in terms of sectoral CO_2 emissions, output and net exports. Many numeric results suggest that OBA-HE and AO have advantageous effects on energy-intensive sectors, in comparison to AUC.

5.4. Effects on other regions

Section 5.3 focuses on the domestic effects of allocation methods. We need consider not only domestic effects but also international ones, in order to figure out the carbon leakage issue. This section examines the effects of emissions abatement on Asian countries, which have strengthened the relation with Japan – China, Korea, and other Asia. For this, we see changes in output and CO_2 emissions in these countries, which are closely related to the carbon leakage.

GF is inferior to other allocation methods not only in terms of economic efficiency but also in terms of the mitigation of the burdens on domestic energy-intensive industries. Moreover, OBA-VA has impacts similar to AUC, and that AO-C is the most efficient method in AO. Thus, we focus on AUC, OBA-HE, and AO-C in this section.

5.4.1. Output in China, Korea, and other Asia

Table 10 represents the changes in output in China, Korea and other Asia in billions of dollars. In China, the increases in output in energy-intensive sectors are the smallest in OBA-HE and the largest in AUC. This means that the relocation of energy-intensive production from Japan to China is the smallest in OBA-HE and the largest in AUC. Notably, the gap in the size of the relocation between OBA-HE and AUC is large in I_S and CHM sectors. AO-C has the similar results to OBA-HE and the increase in energy-intensive output in China is small.

On the other hand, non-energy intensive production tends to decrease in AUC. This is attributed to the fact that available resources (intermediate inputs and primary factors) for non-energy-intensive sectors decrease with the increase in energy-intensive production. Similarly, output in service sectors generally decreases the most in AUC.

The results show that energy-intensive production relocates from abating regions to China. In addition, we can see that the size of relocation is small in OBA-HE and AO-C and large in AUC. The similar qualitative results are found in Korea and other Asia, even though the size of relocation is much smaller.

5.4.2. CO_2 Emissions in China, Korea, and other Asia.

Table 11 reports additional CO_2 emissions in China, Korea, and other Asia. In China, CO_2 emissions from energy-intensive sectors, in particular, electricity and TEEI sectors increase with the increases in output. At the same time, CO_2 emissions in non-energy-intensive sectors (NEINT) and service sectors (SVCES) do increase as well, even though the production in many of these sectors decline. This is attributed to the fact that the fall in abating countries' demand for primary energy would lower the international prices and encourage substitution from non-primary-energy input to primary energy in China. CO_2 emissions in electricity and TEEI sectors other than I_S (iron and steel) are not so affected by the differences in allocation method. CO_2 emissions in steel sector, however, differ between AUC and OBA-HE. This indicates that the leakage in I_S plays an important role in determining the total leakage. The same qualitative results hold also for Korea and other Asia, even though the leakage to them is much smaller.

5.5. Comparison of allocation methods

We have compared allocation methods in Japan from various perspectives. We now turn to a comprehensive evaluation of allocation methods. First, in terms of economic efficiency, AUC is the best, followed by AO-C, AO-B, OBA-VA, AO-A, OBA-HE, and GF. On the other hand, in terms of the carbon leakage, OBA-HE and AO are superior to AUC, GF and OBA-VA. In addition, in terms of the impacts on energy-intensive sectors, OBA-HE and AO are desirable and AUC and GF are not.

GF is inferior to all allocation methods from all three perspectives: economic efficiency, restraining of leakage, and the mitigation of the burden on domestic energy-intensive sectors. It follows that GF is the undesirable allocation method from various perspectives. There are two reasons for GF's inferiority. First, it has a small positive revenue-recycling effect. Second, it has a strong negative tax-interaction effect.

AUC is the most desirable allocation method in terms of economic efficiency. AUC, however, not only leads to the large leakage but also has considerable negative impacts on domestic energy-intensive sectors. OBA-VA is similar or slightly inferior to AUC in terms of the leakage and the impacts on energy-intensive sectors and clearly inferior to AUC in terms of efficiency. It follows that OBA-VA is inferior to AUC.

OBA-HE is much inferior to AUC in terms of economic efficiency but generates the small leakage and has small negative impacts on energy-intensive sectors. AO-A has similar effects to OBA-HE but is slightly superior to. The difference in AO-A and OBA-HE is that the allocation of permits to non-energy intensive sectors and services sectors is done by auction in the former and by OBA in the latter. The fact that AO-A and OBA-HE have the similar impacts means that the choice of auction and OBA to non-energy intensive sectors and services sectors has small impacts on the results.

AO-B and AO-C is superior to AO-A in terms of efficiency. In particular, the efficiency of AO-C is very close to that of AUC and at the same time its impacts on TEEI sectors is far smaller than AUC. However, since AO-C give no gratis permits to electricity and transport sectors, its impacts on these sectors are almost the same as those of AUC.

In summary, if we put a high priority on efficiency, AUC is the most desirable allocation method. However, if we give consideration to the leakage and the negative impacts on the domestic energy-intensive sectors as well, AO is rather preferable. In particular, AO-C is the well-balanced allocation method in the sense that it has the efficiency very close to AUC and at the same time alleviates the leakage and the burden of TEEI sectors. Economists often evaluate the policy on the basis of only economic efficiency, and thereby tend to support the auction method. When giving consideration to other perspectives, however, other allocation methods may be more desirable, even though it is somewhat less efficient. Indeed, our quantitative analysis supports that the combined schemes of output-based allocation (OBA) and auction (AUC) can be a well-balanced allocation method.

5.6. Discussions

OBA-HE and AO can reduce the burden on domestic energy-intensive industries, which is one of the advantages for these two allocation methods. However, we have to pay attention to two issues. The first issue is shift of the burden of emissions abatement. To reduce the burden on domestic energy-intensive sectors, OBA-HE and AO-A lead to higher permit prices. As a result, households are required to decrease CO2 emission more under these allocation methods than other scenarios. This means that these allocation methods shift the burden of emissions reductions from industrial sectors to the household sector. In political decision-making, we must consider whether such a shift is acceptable or not.

The other issue is the possibility of excessive protection of domestic energy-intensive industries. Although OBA-HE and AO-A reduce the burden on domestic energy-intensive sectors, the decreases in non-energy-intensive sectors become larger than those in energy- intensive sectors, as discussed in Section 5.3.2. That is, these allocation methods protect energy-intensive sectors excessively[14] rather than just reduce their burden. Such an excessive protection would raise a problem for equity. We can prevent, however, this issue by adjusting the amount of gratis permits. Therefore, a careful design of OBA can avoid this type of excessive protection.

6. Conclusions

Using a static CGE model analysis, this paper examines the impacts of various allocation methods of emission permits in Japanese domestic emissions trading scheme. The model has 14 regions and 27 sectors. We employ the GTAP 7 database, with 2004 as the base year. Our analysis assumes that Japan, the U.S., and the EU 27 countries implements a cap and trade scheme to reduce CO_2 emissions by 30%, 20%, and 16%, respectively, from 2004 levels. With these model and assumptions, we have explored how allocation methods affect economy and CO_2 emissions. We compare seven allocation methods: Auctioning (AUC), grandfathering (GF), output-based allocation

[14] OBA may also raise the issue of WTO compatibility. It is, however, beyond the scope of our paper since we focus on economic analysis.

with sectoral distribution based on historical value-added shares (OBA-VA), output-based allocation with sectoral distribution based on historical CO_2 emissions (OBA-HE) and the three combined schemes output-based allocation and auction (AO:AO-A, AO-B, AO-C).

Important results of our analysis are summarized as follow. First, in terms of economic efficiency, AUC is the most desirable allocation method, followed by the AO-C, AO-B, OBA-VA, AO-A, OBA-HE and, lastly, the GF. On the other hand, in the terms of restraining carbon leakage, the results ranked the allocation methods as follows: OBA-HE, AO-A, AO-B, AO-C, GF, AUC, and OBA-VA. Furthermore, our analysis shows that, to reduce the burden on domestic energy-intensive industries, AO-A and OBA-HE are desirable and AUC and GF undesirable.

From these results, it can be said that the AUC method is the best allocation method if the top priority is given to economic efficiency. The AUC method, however, has considerable negative impacts on carbon leakage and on domestic energy-intensive industries. If we also give consideration to the leakage and the negative impacts on the domestic energy-intensive sectors, AO is rather preferable. In particular, AO-C is the well-balanced allocation method in the sense that it has the efficiency very close to AUC and at the same time alleviates the leakage and the burden of TEEI sectors. However, we also find that AO (or OBA-HE) might shift the burden of emissions reduction from domestic energy-intensive industries to the household sector and may protect energy-intensive industries excessively. In selecting allocation methods, policymakers should be aware of the trade-off between the protections of the trade- exposed energy-intensive industry and the burden of households.

References

Armington, P.S. (1969), “A theory of demand for products distinguished by place of production,” IMF Staff Pap. 16.

Ballard, C. L. (2000), “How Many Hours Are in a Simulated Day? The Effects of Time Endowment on the Results of Tax-Policy Simulation Models,” Department of Economics, Michigan State University, Working Paper.

Bernard, Alain L., Carolyn Fischer, and Alan K. Fox (2007) , “Is there a rationale for output-based rebating of environmental levies? “*Resource and Energy Economics* **29**, 83-101.

Böhringer, Christoph and Andreas Lange (2005), “Economic Implications of Alternative Allocation Schemes for Emission Allowances,” *Scandinavian Journal of Economics* **107**(3), 563-581.

Bovenberg, A. Lans and Lawrence H. Goulder (2002), “Environmental Taxation,” in Auerbach, Alan J. and Martin Feldstein eds. *Handbook of Public Economics* **3**, Amsterdam: North-Holland, Chap. 21, 1471-1545.

Demailly, Damien and Philippe Quirion (2008), "European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry," *Energy Economics* **30**, 2009-2027.

Dissou, Yazid (2006), "Efficiency and Sectoral Distributional Impacts of Output-Based Emissions Allowances in Canada," *Contributions to Economic Analysis & Policy* **5** (1).

ESRI (2007), *Annual Report on National Accounts: 2007*, Economic and Social Research Institute ({ESRI}), Cabinet Office, Government of Japan. In Japanese.

Fischer, C. and A. K. Fox (2007), "Output-Based Allocation of Emission Permits for Mitigating Tax and Trade Interactions, *"Land Economics* **83** (4), 575-599.

Fischer, Carolyn (2001), "Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards." July 2001, Resources for the Future Discussion Paper 01-22.

Fullerton, Don and Gilbert E. Metcalf (2001), "Environmental Controls, Scarcity Rents, and Pre-Existing Distortion," *Journal of Public Economics* **80**, 249-267.

Goulder, Lawrence H., Ian W. H. Parry, Roberton C. Williams, and Dallas Burtraw (1999), "The Cost-Effectiveness of Alternative Instruments for Environmental Protection in a Second-Best Setting," *Journal of Public Economics* **72**, 329-360.

GTAP (2008), Global Trade Analysis Project, GTAP 7 Data Package, University of Purdue.

Hatano, Toshiya and Masahiro Yamada (2007), "The household behavior and the effects of public policy: investigation and estimation of structural parameters", Toshiaki Tachibanaki ed. *The size of Government and Social Security System*, pp.203-222, Tokyo, Tokyo University Press. In Japanese.

Jensen, Jesper and Tobias N. Rasmussen (2000), "Allocation of CO_2 Emissions Permits: A General Equilibrium Analysis of Policy Instruments," *Journal of Environmental Economics and Management* **40**, 111-136.

Lee, Huey-Lin (2008) "The Combustion-based CO2 Emissions Data for GTAP Version 7 Data Base," https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1143.

MHLW (2008), "Monthly Labor Survey", Ministry of Health, Labor and Welfare. In Japanese.

MFPRI (2008), "Fiscal and Financial Statistical Monthly (672)", Ministry of Finance, Policy Research Institute. In Japanese.

Parry, Ian W. H., Roberton C. Williams III, and Lawrence H. Goulder (1999), "When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets," *Journal of Environmental Economics and Management*, **37**, 52-48.

Rutherford, T. F. and S. V. Paltsev (2000), "GTAP in GAMS and GTAP-EG: Global Datasets for

Economic Research and Illustrative Models," Department of Economics, University of Colorado, Working Paper.

Shiro Takeda (2007), "The Double Dividend from Carbon Regulations in Japan", *Journal of the Japanese and International Economies*, 21, 336-364.

Table 1: The list of regions and sectors

Symbol	Regions
USA	United States
CAN	Canada
JPN	Japan
OOE	Other OECD
EUR	EU27
FSU	Former Soviet Union
OEU	Other Europian regions
CHN	China (including Hong Kong + Taiwan)
KOR	Korea
IND	India
BRA	Brazil
ASI	Other Asia
MPC	Mexico + OPEC
ROW	Rest of world

Symbol	Sectors
ELY	Electricity
FSH	Fishery
OMN	Other mining
SGR	Sugar
PPP	Paper-pulp-print
CRP	Chemical industry
NMM	Non-metallic minerals
I_S	Iron and steel industry
OTP	Transport nec
WTP	Water transport
ATP	Air transport
AGR	Agriculture
FPR	Food products
TWL	Textiles-wearing apparel-leather
LUM	Wood and wood-products
NFM	Non-ferrous metals
TRN	Transport equipment
OME	Other machinery
OMF	Other manufacturing
COL	Coal
OIL	Crude oil
GAS	Gas
P_C	Petroleum and coal products (refined)
CNS	Construction
TRD	Trade
CMN	Communication
SER	Commercial and public services

Table 2: The list of scenarios.

Symbol	Scenario
AUC	All permits are allocated by auction.
GF	Gratis allocation by grandfathering.
OBA-VA	Intra-industry allocation is based on OBA and inter-industry allocation is based on historical value-added share.
OBA-HE	Intra-industry allocation is based on OBA and inter-industry allocation is based on historical emissions share.
AO-A	OBA-HE for energy-intensive sectors and auction for other sectors.
AO-B	OBA-HE for energy-intensive sectors (excl. electricity) and auction for other sectors.
AO-C	OBA-HE for energy-intensive sectors (excl. electricity and transport) and auction for other sectors.

Table 3: Initial allocation of permits in Japan (MtCO2)

	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
ELY	12.3	277.9	277.9	0.0	0.0
FSH	1.3	10.1	10.1	10.1	10.1
OMN	0.7	1.7	1.7	1.7	1.7
SGR	0.2	0.4	0.4	0.4	0.4
PPP	11.8	9.5	9.5	9.5	9.5
CRP	17.2	46.4	46.4	46.4	46.4
NMM	4.8	15.8	15.8	15.8	15.8
I_S	6.5	107.3	107.3	107.3	107.3
OTP	29.0	119.3	119.3	119.3	0.0
WTP	3.6	13.1	13.1	13.1	0.0
ATP	1.4	8.7	8.7	8.7	0.0
AGR	9.1	10.5	0.0	0.0	0.0
FPR	16.3	7.1	0.0	0.0	0.0
TWL	4.0	0.4	0.0	0.0	0.0
LUM	1.8	0.0	0.0	0.0	0.0
NFM	2.8	1.8	0.0	0.0	0.0
TRN	15.5	0.1	0.0	0.0	0.0
OME	21.9	1.4	0.0	0.0	0.0
OMF	34.8	6.1	0.0	0.0	0.0
COL	0.0	0.0	0.0	0.0	0.0
OIL	0.0	0.0	0.0	0.0	0.0
GAS	0.0	0.0	0.0	0.0	0.0
P_C	0.5	8.2	0.0	0.0	0.0
CNS	47.0	8.2	0.0	0.0	0.0
TRD	112.8	10.5	0.0	0.0	0.0
CMN	17.2	1.1	0.0	0.0	0.0
SER	348.2	55.1	0.0	0.0	0.0
Gratis alloc.	720.7	720.7	610.2	332.3	191.2
Auction	112.5	112.5	223.0	500.9	642.0
Total	833.2	833.2	833.2	833.2	833.2

Gratis alloc.: the total amount of gratis permits.

Auction: the total amount of permits by auction.

Total: the total emissions cap.

Table 4: Macroeconomic indicators in Japan.

	AUC	GF	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
Permit price ($/tCO2)	99.0	93.7	100.0	133.7	131.6	107.5	105.6
Welfare	-0.25	-0.60	-0.38	-0.49	-0.47	-0.36	-0.31
Real GDP	-0.06	-1.10	-0.47	-0.65	-0.56	-0.30	-0.23
Consumption	0.10	-1.71	-0.62	-0.95	-0.80	-0.36	-0.19
Export	-5.27	-5.86	-5.50	-5.07	-4.98	-4.58	-5.62
Total production	-0.76	-1.61	-1.08	-1.04	-0.97	-0.91	-0.84
Labor supply	0.89	-0.91	0.17	-0.01	0.15	0.50	0.63
Leisure	-0.63	0.64	-0.12	0.01	-0.11	-0.35	-0.44
Wage rate	1.00	-3.20	-0.69	-1.31	-0.95	-0.01	0.35
Labor tax rate (%)	44.3	51.8	49.6	50.5	49.4	46.9	45.7
Labor income	1.90	-4.08	-0.52	-1.32	-0.80	0.48	0.98
HH income	0.10	-1.71	-0.62	-0.95	-0.80	-0.36	-0.19
Value of net permit rev (bil$)	82.5	10.5	11.3	15.0	29.3	53.8	67.8
Leakage rate (%)	16.1	16.1	16.1	15.3	15.3	15.6	15.6
Leakage rate (unilateral, %)	36.9	36.6	36.9	32.4	32.6	33.8	34.2

Percentage change from BaU unless otherwise indicated.

Leakage (unilateral, %): the leakage rate when Japan reduces its emissions unilaterally.

Table 5: Leakage to non-abating regions by sector ($MtCO_2$).

	AUC	GF	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
ELY	195.6	195.5	195.8	189.6	189.8	192.6	191.5
FSH	0.6	0.6	0.6	0.6	0.6	0.6	0.6
OMN	2.6	2.6	2.6	2.5	2.5	2.5	2.5
SGR	0.2	0.2	0.2	0.2	0.2	0.2	0.2
PPP	2.3	2.3	2.3	2.5	2.4	2.4	2.4
CRP	25.8	25.8	25.9	25.0	24.9	25.3	25.1
NMM	16.9	16.9	16.9	15.5	15.4	16.0	16.0
I_S	29.8	29.6	30.0	19.5	19.4	21.2	21.1
TEEI	78.2	78.0	78.5	65.7	65.4	68.3	67.9
OTP	25.1	25.1	25.1	25.1	25.2	24.9	25.5
WTP	5.4	5.4	5.4	5.3	5.4	5.2	5.7
ATP	15.1	14.9	15.0	14.6	14.6	14.4	15.5
TRANS	45.6	45.3	45.5	45.1	45.2	44.5	46.7
AGR	1.9	1.8	1.9	2.1	2.2	2.1	2.1
FPR	2.1	2.0	2.1	2.2	2.2	2.2	2.2
TWL	0.9	0.9	0.9	1.2	1.2	1.1	1.1
LUM	0.3	0.3	0.3	0.3	0.3	0.3	0.3
NFM	5.4	5.5	5.4	5.4	5.5	5.9	5.8
TRN	0.4	0.4	0.4	0.5	0.5	0.5	0.5
OME	1.1	1.2	1.1	1.4	1.4	1.3	1.2
OMF	3.2	3.2	3.2	3.5	3.5	3.4	3.4
NEINT	15.3	15.4	15.3	16.7	16.8	16.8	16.7
COL	-3.2	-3.2	-3.2	-3.4	-3.4	-3.4	-3.4
OIL	-4.0	-4.0	-4.0	-4.2	-4.2	-4.1	-4.1
GAS	-10.1	-10.1	-10.1	-10.4	-10.3	-10.3	-10.3
P_C	7.6	7.5	7.6	7.0	7.5	7.5	7.6
ENES	-9.8	-9.9	-9.8	-10.9	-10.4	-10.3	-10.1
CNS	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TRD	2.3	2.3	2.3	2.4	2.4	2.4	2.3
CMN	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SER	4.8	4.8	4.8	5.0	5.0	5.0	5.0
SVCES	8.5	8.4	8.4	8.9	8.8	8.8	8.7
HH	19.7	19.6	19.6	20.7	20.8	20.7	20.3
SUM	353.2	352.3	353.3	335.8	336.5	341.4	341.7

TEEI: trade-exposed energy-intensive sectors as a whole.

TRANS: transport sectors as a whole.

NEINT: non-energy intensive sectors as a whole.

ENES: energy sectors as a whole.

SVCES: services sectors as a whole.

HH: the representative household.

Table 6: Leakage to non-abating regions ($MtCO_2$)

	AUC	GF	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
CHN	69.7	69.4	69.8	61.3	61.3	63.7	63.4
KOR	10.9	10.9	10.9	10.0	10.0	10.1	10.1
ASI	34.2	34.0	34.2	32.6	32.6	33.1	33.3
CAN	19.7	19.7	19.7	19.5	19.5	19.6	19.7
OOE	15.2	15.2	15.2	14.7	14.8	15.2	15.3
FSU	72.9	72.8	72.9	70.2	70.1	70.8	70.8
OEU	6.2	6.2	6.2	6.1	6.1	6.1	6.2
IND	17.4	17.4	17.4	17.0	17.1	17.3	17.1
BRA	4.9	4.8	4.9	4.5	4.5	4.5	4.6
MPC	39.3	39.2	39.3	38.5	38.9	39.0	39.2
ROW	62.8	62.7	62.8	61.5	61.6	61.8	62.0
Total	353.2	352.3	353.3	335.8	336.5	341.4	341.7

Table 7: Change in CO_2 emissions ($MtCO_2$)

	AUC	GF	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
ELY	-171.4	-170.4	-170.8	-163.0	-162.4	-175.4	-174.3
FSH	-2.4	-2.6	-2.5	-2.6	-2.7	-2.3	-2.2
OMN	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
SGR	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
PPP	-4.0	-4.0	-4.0	-3.9	-3.8	-4.1	-4.1
CRP	-18.9	-18.9	-18.9	-18.6	-18.5	-18.9	-18.7
NMM	-7.3	-7.2	-7.3	-7.2	-7.2	-7.4	-7.3
I_S	-59.0	-58.4	-59.0	-52.5	-52.3	-52.6	-52.2
TEEI	-92.2	-91.6	-92.1	-85.3	-85.0	-85.8	-85.1
OTP	-31.0	-31.3	-30.9	-33.8	-33.9	-30.6	-32.5
WTP	-4.1	-4.0	-4.0	-4.5	-4.5	-3.9	-4.3
ATP	-2.6	-2.6	-2.6	-2.6	-2.6	-2.2	-2.9
TRANS	-37.7	-37.9	-37.6	-40.9	-41.0	-36.8	-39.6
AGR	-3.0	-3.0	-3.0	-3.5	-3.7	-3.2	-3.2
FPR	-1.8	-1.8	-1.8	-1.7	-1.7	-1.9	-1.9
TWL	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
LUM	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NFM	-0.5	-0.5	-0.4	-0.4	-0.4	-0.5	-0.5
TRN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OME	-0.3	-0.3	-0.3	-0.2	-0.2	-0.3	-0.3
OMF	-2.0	-1.9	-1.9	-1.7	-1.7	-2.1	-2.0
NEINT	-7.6	-7.7	-7.5	-7.6	-7.8	-8.1	-8.0
COL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OIL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GAS	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_C	-1.7	-1.8	-1.7	-1.7	-1.8	-1.7	-1.7
ENES	-1.7	-1.8	-1.7	-1.7	-1.8	-1.7	-1.7
CNS	-2.4	-2.3	-2.3	-2.6	-2.7	-2.5	-2.4
TRD	-2.0	-2.1	-2.0	-1.6	-1.6	-2.2	-2.1
CMN	-0.2	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2
SER	-15.1	-15.2	-14.9	-14.1	-14.1	-15.9	-15.7
SVCES	-19.7	-19.8	-19.4	-18.5	-18.6	-20.8	-20.5
HH	-26.8	-28.0	-28.0	-40.1	-40.5	-28.5	-27.9
SUM	-357.1	-357.1	-357.1	-357.1	-357.1	-357.1	-357.1

Table 8: Percentage change in output (%).

	AUC	GF	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
ELY	-12.6	-13.1	-12.6	-4.6	-4.6	-12.9	-12.7
FSH	-3.6	-4.4	-3.9	-3.5	-3.6	-2.8	-2.6
OMN	-2.0	-2.2	-2.1	-1.1	-1.0	-1.4	-1.5
SGR	-0.6	-2.0	-1.2	-1.1	-1.2	-0.7	-0.5
PPP	-0.3	-1.5	-0.8	-0.9	-0.8	-0.7	-0.6
CRP	-3.0	-3.8	-3.3	-1.6	-1.5	-1.9	-1.7
NMM	-2.1	-2.5	-2.3	-0.9	-0.8	-1.2	-1.2
I_S	-11.3	-11.5	-11.5	-2.7	-2.6	-4.2	-4.0
TEEI	-4.0	-4.7	-4.4	-1.6	-1.5	-2.1	-1.9
OTP	-1.7	-2.8	-2.2	-1.2	-1.0	-0.7	-2.1
WTP	-2.6	-3.0	-2.8	-1.5	-1.4	-1.0	-3.3
ATP	-3.8	-4.7	-4.3	-0.5	-0.2	0.9	-5.6
TRANS	-1.9	-3.0	-2.4	-1.2	-1.0	-0.6	-2.5
AGR	-0.5	-1.6	-0.9	-1.3	-2.1	-1.3	-1.1
FPR	-0.2	-1.7	-0.8	-1.1	-1.4	-0.8	-0.5
TWL	1.6	-0.2	0.9	-1.4	-1.2	-0.3	0.0
LUM	0.6	0.0	0.4	-1.1	-1.1	-0.6	-0.6
NFM	-3.2	-3.8	-3.5	-2.3	-3.0	-5.2	-4.9
TRN	-0.2	-1.2	-0.5	-1.7	-1.3	-0.4	-0.2
OME	-0.9	-1.6	-1.1	-2.3	-2.0	-1.8	-1.4
OMF	-0.8	-1.7	-1.1	-1.7	-1.7	-1.7	-1.5
NEINT	-0.6	-1.5	-0.9	-1.7	-1.6	-1.3	-1.0
P_C	-14.6	-15.0	-14.7	-14.5	-15.5	-14.7	-14.8
ENES	-14.6	-15.0	-14.7	-14.5	-15.5	-14.7	-14.8
CNS	-0.2	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2
TRD	0.5	-0.9	0.0	-0.7	-0.5	-0.1	0.2
CMN	0.5	-0.8	0.0	-0.7	-0.5	-0.1	0.1
SER	0.2	-0.8	-0.2	-0.6	-0.5	-0.3	-0.1
SVCES	0.2	-0.8	-0.2	-0.6	-0.5	-0.2	-0.1
SUM	-0.8	-1.6	-1.1	-1.0	-1.0	-0.9	-0.8

Table 9: Change in net export (billions of US$).

	AUC	GF	OBA-VA	OBA-HE	AO-A	AO-B	AO-C
FSH	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
OMN	0.6	0.7	0.7	0.2	0.2	0.4	0.4
SGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PPP	-0.1	-0.1	-0.1	-0.1	0.0	-0.2	-0.2
CRP	-6.6	-6.1	-6.5	-1.8	-1.6	-3.3	-3.1
NMM	-1.0	-0.9	-1.0	-0.2	-0.1	-0.4	-0.5
I_S	-10.7	-10.3	-10.8	-1.2	-1.2	-3.0	-3.0
TEEI	-17.9	-16.8	-17.9	-3.2	-2.9	-6.6	-6.5
OTP	-0.5	-0.4	-0.4	-0.1	-0.1	0.0	-0.8
WTP	-0.7	-0.7	-0.7	-0.4	-0.3	-0.1	-1.0
ATP	-0.5	-0.4	-0.5	0.3	0.3	0.6	-1.1
TRANS	-1.7	-1.4	-1.6	-0.2	-0.1	0.5	-2.9
AGR	-0.1	0.4	0.1	-0.1	-0.4	-0.3	-0.3
FPR	-0.1	0.7	0.2	-0.5	-0.8	-0.6	-0.7
TWL	0.8	1.1	1.0	-0.3	-0.3	-0.1	-0.1
LUM	0.3	0.3	0.3	0.0	-0.1	0.1	0.0
NFM	-0.9	-0.8	-0.9	-0.2	-0.6	-1.6	-1.5
TRN	-0.3	-1.5	-0.7	-3.7	-2.9	-0.9	-0.4
OME	-2.5	-4.2	-3.0	-6.5	-5.8	-5.1	-4.1
OMF	-2.2	-3.3	-2.5	-5.5	-6.0	-6.1	-5.6
NEINT	-5.0	-7.3	-5.5	-16.8	-16.9	-14.7	-12.8
COL	3.3	3.3	3.3	3.3	3.3	3.3	3.3
OIL	7.7	7.9	7.7	7.5	8.0	7.7	7.8
GAS	4.7	4.6	4.7	4.8	4.7	4.8	4.7
P_C	1.0	1.1	1.0	1.3	0.8	0.8	0.8
ENES	16.6	16.8	16.6	16.9	16.9	16.6	16.7
CNS	0.1	0.0	0.1	-0.2	-0.3	-0.1	-0.1
TRD	0.7	0.7	0.7	-0.3	-0.3	0.0	0.0
CMN	0.1	0.1	0.1	0.0	0.0	0.0	0.0
SER	1.8	2.1	2.0	-1.2	-1.3	-0.3	-0.1
SVCES	2.7	2.9	2.9	-1.8	-1.9	-0.4	-0.2
SUM	-5.3	-5.9	-5.5	-5.1	-5.0	-4.6	-5.6

Table 10: Change in output in China, Korea and other Asia (billions of US$).

	CHN			KOR			ASI		
	AUC	OBA-HE	AO-C	AUC	OBA-HE	AO-C	AUC	OBA-HE	AO-C
ELY	1.41	1.19	1.24	0.37	0.28	0.29	0.78	0.71	0.72
FSH	0.07	0.07	0.06	0.03	0.03	0.03	0.03	0.03	0.03
OMN	0.56	0.28	0.38	0.03	0.01	0.02	0.09	0.09	0.11
SGR	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
PPP	0.18	0.24	0.25	0.05	0.06	0.06	0.24	0.24	0.24
CRP	3.65	2.85	3.01	2.16	1.84	1.89	3.59	2.81	2.95
NMM	1.04	0.72	0.82	0.21	0.09	0.13	0.52	0.42	0.45
I_S	5.79	1.53	2.20	2.71	0.38	0.78	1.23	0.48	0.61
TEEI	11.29	5.68	6.72	5.18	2.41	2.91	5.70	4.06	4.39
OTP	1.52	1.37	1.54	0.51	0.45	0.50	1.35	1.31	1.37
WTP	0.48	0.39	0.46	-0.02	-0.01	-0.01	0.36	0.33	0.38
ATP	1.24	1.14	1.30	0.41	0.38	0.42	1.33	1.26	1.36
TRANS	3.24	2.90	3.31	0.90	0.81	0.91	3.04	2.91	3.11
AGR	0.04	0.13	0.15	0.03	0.03	0.03	0.07	0.06	0.06
FPR	-0.04	0.10	0.11	0.03	0.07	0.07	-0.01	0.01	0.03
TWL	-1.62	-0.75	-0.95	-0.09	-0.01	-0.03	0.40	0.36	0.29
LUM	-0.33	-0.20	-0.26	-0.01	-0.01	-0.01	-0.05	0.01	-0.03
NFM	0.70	0.64	0.98	-0.04	-0.07	0.00	0.33	0.27	0.41
TRN	0.06	0.47	0.15	-0.77	-0.11	-0.40	0.06	0.34	0.16
OME	-1.42	0.42	-0.57	-1.48	-0.78	-1.02	-0.13	0.39	0.13
OMF	-1.22	0.53	0.22	-1.21	-0.76	-0.66	0.75	2.14	1.80
NEINT	-3.83	1.34	-0.17	-3.53	-1.64	-2.03	1.42	3.57	2.85
COL	-1.10	-1.18	-1.16	0.00	0.00	0.00	-0.52	-0.53	-0.53
OIL	-0.57	-0.63	-0.60	0.00	0.00	0.00	-0.66	-0.72	-0.70
GAS	-0.16	-0.16	-0.16	0.00	0.00	0.00	-1.34	-1.41	-1.39
P_C	1.39	0.99	1.14	1.05	0.85	0.95	1.18	1.06	1.15
ENES	-0.44	-0.98	-0.78	1.05	0.85	0.95	-1.34	-1.60	-1.47
CNS	-0.03	0.00	-0.01	0.01	0.01	0.01	-0.03	-0.01	-0.02
TRD	-0.28	0.08	-0.04	-0.01	0.08	0.05	0.23	0.34	0.29
CMN	-0.06	-0.03	-0.04	-0.01	0.01	0.00	-0.02	-0.02	-0.03
SER	-0.98	-0.64	-0.75	-0.19	-0.01	-0.06	-0.56	-0.53	-0.55
SVCES	-1.35	-0.59	-0.84	-0.20	0.09	0.00	-0.39	-0.22	-0.30
SUM	10.32	9.54	9.48	3.78	2.81	3.03	9.22	9.44	9.32

Table 11: Change in CO2 emissions in China, Korea and other Asia (MtCO2).

	CHN			KOR			ASI		
	AUC	OBA-HE	AO-C	AUC	OBA-HE	AO-C	AUC	OBA-HE	AO-C
ELY	42.67	39.38	40.23	5.66	5.19	5.23	12.33	11.94	12.06
FSH	0.24	0.25	0.24	0.08	0.08	0.07	0.15	0.15	0.15
OMN	0.34	0.25	0.28	0.01	0.01	0.01	0.16	0.16	0.18
SGR	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02
PPP	0.39	0.44	0.44	0.04	0.04	0.04	0.41	0.42	0.42
CRP	4.23	3.86	3.94	0.23	0.22	0.22	3.45	3.06	3.13
NMM	6.75	5.76	6.11	0.54	0.46	0.49	3.85	3.51	3.63
I_S	7.84	3.28	3.99	0.84	0.29	0.38	1.82	0.94	1.09
TEEI	19.79	13.83	14.99	1.75	1.09	1.21	9.86	8.28	8.62
OTP	2.19	2.19	2.26	1.15	1.11	1.15	2.99	3.01	3.07
WTP	1.50	1.43	1.51	0.06	0.07	0.07	0.81	0.80	0.86
ATP	1.24	1.17	1.29	0.57	0.54	0.59	3.20	3.09	3.28
TRANS	4.93	4.79	5.07	1.79	1.72	1.81	7.00	6.90	7.20
AGR	0.80	0.92	0.90	0.05	0.05	0.05	0.11	0.12	0.12
FPR	0.40	0.48	0.47	0.04	0.05	0.05	0.37	0.39	0.39
TWL	0.13	0.29	0.25	0.04	0.06	0.05	0.19	0.20	0.19
LUM	0.02	0.05	0.04	0.00	0.00	0.00	0.03	0.03	0.03
NFM	0.55	0.53	0.69	0.01	0.01	0.01	0.20	0.18	0.23
TRN	0.17	0.22	0.18	0.03	0.05	0.04	0.05	0.06	0.05
OME	0.20	0.39	0.29	0.00	0.00	0.00	0.17	0.23	0.21
OMF	0.08	0.14	0.13	0.00	0.01	0.01	0.53	0.66	0.63
NEINT	2.35	3.01	2.96	0.17	0.23	0.21	1.65	1.87	1.84
COL	-2.46	-2.63	-2.60	0.00	0.00	0.00	-0.11	-0.11	-0.11
OIL	-0.68	-0.75	-0.72	0.00	0.00	0.00	-0.15	-0.17	-0.16
GAS	-2.86	-2.98	-2.96	0.00	0.00	0.00	-0.40	-0.42	-0.42
P_C	0.04	0.03	0.04	0.00	0.00	0.00	0.96	0.87	0.94
ENES	-5.96	-6.33	-6.24	0.00	0.00	0.00	0.30	0.17	0.25
CNS	0.23	0.26	0.25	0.03	0.03	0.03	0.08	0.09	0.09
TRD	0.41	0.48	0.45	0.07	0.08	0.08	0.46	0.49	0.48
CMN	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.02	0.02
SER	0.53	0.60	0.58	0.31	0.34	0.33	0.76	0.79	0.79
SVCES	1.19	1.35	1.30	0.42	0.46	0.44	1.33	1.40	1.38
HH	4.70	5.26	5.06	1.16	1.27	1.22	1.79	2.06	1.97
SUM	69.67	61.30	63.37	10.95	9.97	10.13	34.25	32.61	33.33

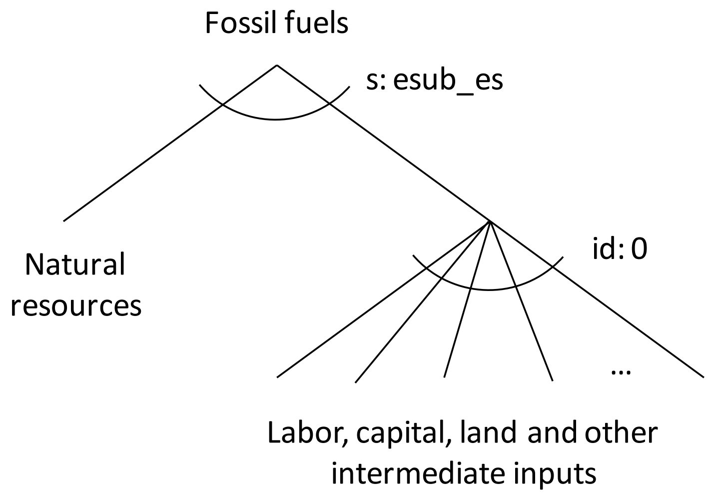


Figure 1: Production function of fossil fuel sectors

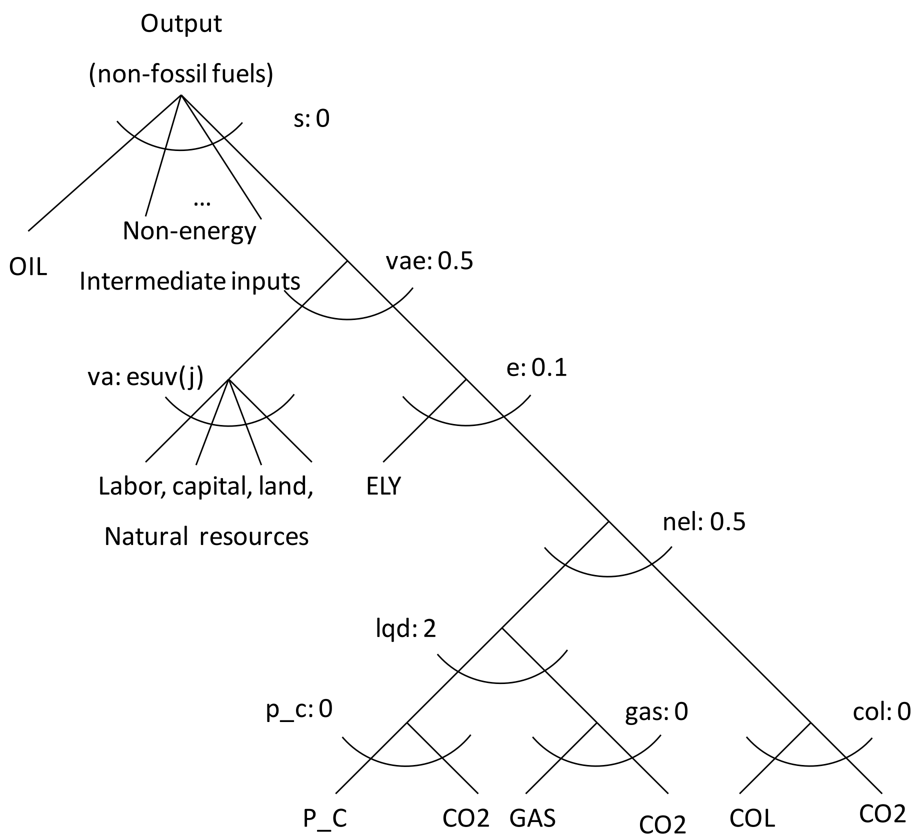


Figure 2: Production function of non-fossil fuel sectors.

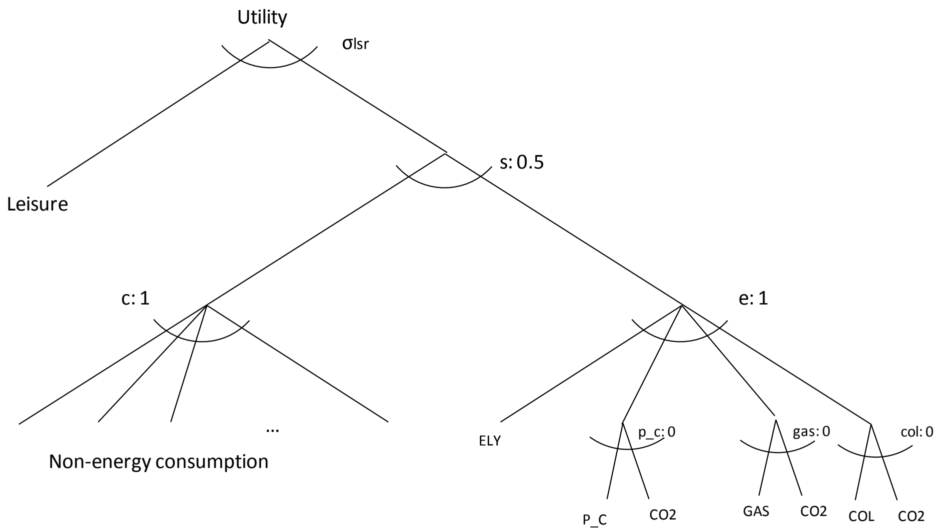


Figure 3: Utility function.

An optimal ad valorem tax with an output refund scheme for permits auction

Yuanguang Yu

Jinhe Center for Economic Research, Xi'an Jiaotong University, Xi'an, China,710049

Abstract

This paper will explore a mechanism to restore the distortions emerging in an imperfect product and the permit auction market. We investigate an ad valorem tax combined with an output refund scheme and derive an expression for the optimal ad valorem tax. We show that this scheme works well on restoring three market distortions: 1) underproduction due to imperfect competition, 2) pollution externality, 3) underpricing brought by uniform price auction. Social optimal output and abatement can be achieved under this scheme. A clearing price equal to a Pigouvian tax will endogenously result in the auction market. Moreover, we introduce an investment of abatement technology into our consideration. We find that the output based refund with the same ad valorem tax setting works well on further leading firms to achieve the social optimal level of the investment in abatement technology.

Keywords: Ad valorem tax; Output refund scheme; Uniform price auction; Underpricing

1. Introduction

Most often a uniform price auction is regarded as the simplest way to allocate public goods, especially for multiple homogeneous goods, such as treasury securities, electricities and emissions permits. Regulator need to aggregate each bidder's demand curve and declare the point at which the aggregate demand curve crosses the supply curve as the clearing price. However, some research finds that using uniform price auction to allocate multiple units of goods would be more likely to lead to a lower equilibrium price than the competitive one. We will call such a lower equilibrium price the "underpricing effect" in the rest part of this paper. Wilson (1979) first demonstrates this problem through a share auction. He finds that under the uniform price auction, share auction can lead to collusive results, and sellers will get lower revenues than what they would get under a unit auction. Back and Zender (1993) prove the existence of a underpricing effect from a perspective of endogenous monopsony power. Under a fixed supply, when bidders are submitting their down-sloping demand functions, each bidder would work as a monopsonist facing an upward-sloping residual supply. A lower equilibrium price than their marginal cost will be the result by exercising this kind of monopsony power. Ausubel (2002) also demonstrates that in a uniform price auction the bidder has an incentive to shade his bid if he desires more than one unit. This underpricing effect would not only cause a loss in seller revenue, but also lead to a misallocation

Email address: yu.yuanguang@gmail.com (Yuanguang Yu)

of auctioned goods. Moreover, it will send a wrong signal to the trading price in the secondary market. Some literature aiming at eliminating this underpricing effect began to emerge one after another. Back and Zender (2001) and LiCalzi and Pavan (2005) explore using a flexible supply to replace the fixed supply, and they show that the underpricing effect can be reduced if the elastic supply is announced before the auction. Kremer and Nyborg (2004) prove that underpricing effect can be reduced by using alternative allocation rules.

There is a wide range of articles focusing on investigating emissions tax as an optimal pollution control instrument under imperfect competition. Buchanan (1969) firstly finds that for a monopolist firm the feasible pollution tax to be levied is less than social marginal damage. Barnett (1980) extends Buchanan's work and gives a more explicit analysis about the relation between social marginal damage and the pollution tax. Levin (1985) demonstrates that a pollution tax can result in a pollution increase rather than a reduction under Cournot oligopoly. Simpson (1995) shows that the optimal emissions tax may exceed the marginal damage for a Cournot duopoly market if firms have different production costs. Although the literature mentioned above carry out the study of optimal tax under imperfect competition from different perspectives, all of them can be merged into one common point that a Pigouvian tax cannot be implemented for an imperfect competition market and regulators must turn to the second best tax setting. Later, Gersbach and Requate (2004) demonstrate an optimal tax refund scheme in an imperfect product market under which the first best outcomes of output and emissions can be achieved. But still the optimal tax that they derived is not equal to Pigouvian tax.

In contrast with the above studies of focusing on analyzing the optimal emissions tax under different market structures, we struggle for developing a mechanism to restore the distortions emerging in the product and the permits markets when a uniform price auction but not a tax is chosen as an instrument to regulate the pollution. Here we should draw a line between emissions tax and emissions auction policies. Although the two regulations are all roughly regarded as price instruments for environmental regulation, the price establishments are quite different from each other. As for emissions tax, the rate is often exogenously determined by the regulator ex ante, and regulated firms have no influence on the magnitude of the tax during its implementation. But for the price in an auction, it is usually endogenously made by regulated firms, and it would be influenced by the choice of auction formats, goods supply and bidding function submitted by the regulated firms.

In this paper, we characterize the equilibriums of product and permit auction markets under the condition that market power will emerge in both markets[1]. Without any doubt, the first best outcomes cannot be achieved in the product and the permits auction market. In the product market, it is well known that imperfectly competitive firms would have an incentive to produce less than the social optimal output level. If regulators tax the emissions to reduce the pollution, it will aggravate the preexisting distortion. In the emissions permits auction market, distinct from traditional a constant marginal value of auctioned goods (Back and Zender , 1993; LiCalzi and Pavan , 2005; Kremer and Nyborg , 2004), here

[1]We regard the underpricing effect as being caused by the monopsony market power

the marginal value for different amount of emissions should be equal to the marginal abatement cost of that emissions level. But still a lower than optimal equilibrium price will be derived, which will definitely lead to a misallocation of permits among these firms.

In this paper, we introduce a refund scheme and an ad valorem tax into our analysis. We show that if we refund the revenues from a uniform price auction based on firm's output shares, the underpricing effect in the auction can be eradicated. If combining the refund scheme with an ad valorem tax in the product market, first best outcomes are achieved in both product and permits markets. A clearing price equal to a Pigouvian tax would endogenously result in a permit auction market. That is a good indicative signal of permit pricing in the secondary emissions trading market. Moreover, we extend the analysis into introducing an abatement investment into the consideration. We find that the refund scheme with the same setting for ad valorem tax still works well on inducing firms to invest in abatement social optimally at the time that first best outcomes occur in both markets.

To the best of our knowledge, Shaffer (1995) was the first to suggest a firm specific ad valorem tax or subsidies to control the externality in an oligopoly industry. He derived an optimal ad valorem tax with a simplified model to make a firm private equilibrium coincide with the social optimal equilibrium. But in his model, he didn't consider the abatement. The emissions are directly related to the output, which means that the reduction of a firm's emissions led by the implementation of an ad valorem tax would inevitably lead the same reduction of the firm's output. That certainly cannot reflect a firm's desire for the abatement.

The rest of the paper is organized as follows. In section 2, we present the basic model. In section 3, we derive an optimal expression for the ad valorem tax under the output refund scheme and discuss our results. In section 4, we will extend our analysis into a consideration of including abatement technology investment. In section 5, we will give our conclusions and further possible research areas.

2. The basic model

We consider an oligopoly industry with n firms. With no loss of generality, firm i produces q^i with a cost function of $C^i(q^i, e^i)$, where is the emissions after abatement. We assume that firm i's cost function satisfies $C^i_q(q^i, e^i) > 0$, $C^i_e(q^i, e^i) < 0$, $C^i_{qq}(q^i, e^i) > 0$, $C^i_{ee}(q^i, e^i) > 0$, $C^i_{qe}(q^i, e^i) = C^i_{eq}(q^i, e^i) < 0$ and $C^i_{qq}(\cdot)C^i_{ee}(\cdot) - C^i_{qe}(\cdot)^2 > 0$. The aggregate output level for the industry is $Q = \sum_{j=1}^{n} q^j$, which is determined endogenously by firms. We assume the emissions cap for the industry is E, which is exogenously determined by the regulator. We denote the inverse demand function in the industry as $P(Q)$, which is known for both the regulators and the firms, with an assumption of $P^{'}(Q) < 0$,$P^{'}(Q)+QP^{''}(Q) < 0$, which is a standard assumption for guaranteeing the stability of equilibrium.

2.1. The firm's behavior

We let $e^j(\tau)$ denote other firms demand at a given price τ except firm i. We assume that all demand functions are non-increasing with respect to permits price τ according to the law of demand. We assume that the aggregate emissions demand should not exceed the cap set by the regulator at any possible clearing price τ. So a constraint $\sum\limits_{j=1}^{n} e^j(\tau) \leq E$ is satisfied. Next we begin to explore the optimal demand function $e^j(\tau)$ for firm i under a uniform price auction. With a complete information, given other firms aggregate demand bidding functions, firm i's objective function is written below

$$Max_{q^i, e^i}\ \pi^i = P(Q) \cdot q^i - C^i(q^i, e^i(\tau)) - \tau \cdot e^i$$

$$st.\ e^i \leq E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)$$

As for picking the optimal bidding demand e^i for each price τ , we take Wilson (1979) insight that when firm i substitutes the binding constraint into its objective function, picking a demand e^i for firm i can be transformed into just picking a clearing price τ on the residual supply function faced by firm i to maximize its profit function.

$$Max_{q^i, \tau}\ \pi = P(Q) \cdot q^i - C^i(q^i, E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)) - \tau \cdot (E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau))$$

The well-known first order conditions for q^i and τ is given by:

$$P(Q) + P'(Q)q^i - C_q^i(q^i, E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)) = 0 \qquad (1)$$

$$C_e^i(q^i, E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)) \sum_{\substack{j=1 \\ j\neq i}}^{n} e_\tau^j - (E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)) + \tau \sum_{\substack{j=1 \\ j\neq i}}^{n} e_\tau^j(\tau) = 0 \qquad (2)$$

The subscripts above refer to the corresponding derivatives. From equation (1), we get $P(Q) - C_q^i(q^i, e^i) = -P'(Q)q^i > 0$, which implies firm i would produce less amount than its social optimal level in the equilibrium due to the market power from imperfect competition. Rearranging equation (2), we get an expression of τ:

$$\tau = -C_e^i(q^i, E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)) + \frac{E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau)}{\sum_{\substack{j=1 \\ j\neq i}}^{n} e_\tau^j(\tau)}$$

We conclude that $\tau < -C_e^i(q^i, E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau))$ since $E - \sum_{\substack{j=1 \\ j\neq i}}^{n} e^j(\tau) > 0$ and $\sum_{\substack{j=1 \\ j\neq i}}^{n} e_\tau^j(\tau) < 0$ obviously hold. The result shows that firm i would finally pick a price which is less than the corresponding marginal abatement cost of emissions won at that price. That indicates that underpricing effect truly exists in the permits auction market.

To sum up, two market distortions originally exist under our assumption, underproduction due to an imperfect competition and resource misallocation due to pollution externality. But we can see that the third distortion "underpricing" is brought in when we engage in taking the auction as an instrument to internalize the externality.

2.2. Social welfare maximization

In this section, we use social welfare maximization as a benchmark that regulators are pursuing. We will derive the first best outcomes of outputs and emissions for each firm. To simplify, we assume all tax revenues are given back to firms and consumers as lump-sum transfers. Next we will characterize the first best outcomes, q^{*i} and e^{*i}, by maximizing the welfare expression with respect to q^i and e^i:

$$MaxW(q,e) = \int_0^Q P(z)dz - \sum_{i=1}^{n} C^i(q^i, e^i) - D(E)$$

The first best conditions for q^i and e^i are

$$P(Q) - C_q^i(q^i, e^i) = 0 \tag{3}$$

$$-C_e^i(q^i, e^i) - D^{'}(E) = 0 \tag{4}$$

Equation (3) shows that regulator would equate the marginal production cost with consumer's willingness to pay. In equation (4), the regulator would equate the marginal abatement cost with the marginal damage. Next we turn to explore an output refunding scheme with a special ad valorem tax to make the first best outcomes derived above be achieved.

3. Output-based refunding linked with ad valorem tax scheme

We let φ denote an ad valorem tax implemented in the product market. Under the output-based refunding scheme with ad valorem tax,firm i's objective profit function is:

$$Max \underset{q^i,\tau}{\pi} = (1-\varphi)P(Q)\cdot q^i - C^i(q^i, E - \sum_{\substack{j=1\\ j\neq i}}^{n} e^j(\tau)) - \tau\cdot(E - \sum_{\substack{j=1\\ j\neq i}}^{n} e^j(\tau)) + \frac{q^i}{Q}\tau E$$

First order conditions are written below:

$$(1-\varphi)P(Q) + (1-\varphi)P^{'}(Q)q^i - C_q^i(q^i, E - \sum_{\substack{j=1\\ j\neq i}}^{n} e^j(\tau)) + \tau E\frac{Q-q^i}{Q^2} = 0$$

$$C_e^i(q^i, E - \sum_{\substack{j=1\\ j\neq i}}^{n} e^j(\tau))\sum_{\substack{j=1\\ j\neq i}}^{n} e_\tau^j - (E - \sum_{\substack{j=1\\ j\neq i}}^{n} e^j(\tau)) + \tau\sum_{\substack{j=1\\ j\neq i}}^{n} e_\tau^j(\tau) + \frac{q^i}{Q}E = 0$$

In a symmetric equilibrium,

$$(1-\varphi)P(Q) + (1-\varphi)P^{'}(Q)q - C_q(q,e) + \tau\frac{E}{n}\frac{n-1}{nq} = 0 \tag{5}$$

$$(n-1)C_e(q,e)e_\tau - \frac{E}{n} + \tau(n-1)e_\tau + \frac{E}{n} = 0 \tag{6}$$

Substituting the above welfare maximizing conditions into the above equations, we get two simplified expressions,

$$-\varphi P(Q) + (1-\varphi)P^{'}(Q)q + \tau\frac{E}{n}\frac{n-1}{nq} = 0 \tag{7}$$

$$-(n-1)D^{'}(E)e_\tau + \tau(n-1)e_\tau = 0 \tag{8}$$

Apparently equation (8) implies $\tau = D^{'}(E)$. In others words, a clearing price equal to a Pigouvian tax would endogenously result by the system. Note that equation (8) is independent of the ad valorem tax, which implies that the output refund plays a full role in fixing the underpricing distortion caused by a uniform price auction, and the ad valorem tax has no influence on permits price formation. Solve equation (7), we get an expression of the ad valorem tax

$$\varphi = \frac{P^{'}(Q^*)q^* + \tau \frac{E}{n}\frac{n-1}{nq^*}}{P(Q^*) + P^{'}(Q^*)q} \tag{9}$$

Where we use q^* and e^* to denote the first-best outcomes for each firm, then in a symmetric situation, $Q^* = nq^*$ represents the best aggregate output level for the industry.

Note further that equation (7) shows that the underproduction distortion caused by an imperfect competition is restored by a combination of an ad valorem tax and an output based auction refund scheme, which is apparently different from the well known tax subsidy scheme[2].

If we let the ad valorem tax of equation (5) equals to zero, that is $\varphi = 0$. In a symmetric situation, the first best production under a sole output refund scheme for each firm satisfy:

$$P(Q) = C_q(q, e) - P^{'}(Q)q - \tau \frac{E}{n}\frac{n-1}{nq} \tag{10}$$

Where $-P^{'}(Q)q$ stands for the magnitude of market power originating from an imperfect competition, and it works to deviate firm's production from the social optimal level in a downward direction. On the contrary, the last item in formula (10) originating from the output refund scheme works just oppositely to lift the production upwards. If the output refund is not enough relative to the magnitude of the market power $P^{'}(Q)q$, that is $-P^{'}(Q)q > \tau E(n-1)/n^2 q$, firm will produce still less than the social optimal level. In this case, a subsidy which numerically equals to the ad valorem tax φ is needed. Notice that the ad valorem tax now becomes negative since the denominator of equation (9) which equals to the marginal revenue is definitely positive under a firm's optimal production level, and the numerator is negative since $-P^{'}(Q)q > \tau E(n-1)/n^2 q$. Oppositely, if the output refund is greater than the magnitude of the market power $P^{'}(Q)q$, that is $-P^{'}(Q)q < \tau E(n-1)/n^2 q$, firm will produce more than the social optimal level. In that case, an ad valorem tax is needed to pull the output back to the social optimal level.

From equation (9) we can see that once the first best output and the emissions level are determined by the regulator, the optimal ad valorem tax is actually a linear function of permits price. Equation (9) gives a clear relation between an optimal ad valorem tax setting and the permits price, under such a setting a first best output level can be achieved no matter what happens in the permits market. From another point of view, if we regard permits price τ as a tax, equation (9) implies that, in the presence of an ad valorem tax, the first best output level cannot be achieved under the classical tax-refund scheme if the ad valorem tax doesn't satisfy the setting of equation (9). Define firm's elasticity of demand as $\eta = \partial q/\partial P \cdot P/q$. Substituting $\tau = D^{'}(E)$ into equation (10), we get a simplified optimal ad valorem tax rate

[2] The optimal subsidy rate and tax rate are respectively given by $\rho = -P^{'}(Q^*)q^*$, $t = D^{'}(E)$

$$\varphi = \frac{\frac{1}{\eta} + D^{'}(E)\frac{E}{n}\frac{n-1}{Q^*P(Q^*)}}{1+\frac{1}{\eta}} \tag{11}$$

Notice that a firm would choose an output level where the elasticity satisfies $\eta < -1$ to maximize its profit under an imperfect competition. So the denominator of formula (11) would not equal to zero at the equilibrium.

Proposition 1. *An optimal ad valorem tax will exit, if and only if the inverse of product demand elasticity satisfy $1/\eta > -(n-1)ED^{'}(E)/nQ^*P(Q^*)$. Under a uniform price auction for permits, first best outcomes of both the product and the permit markets can be achieved by combining such a tax with an output refund scheme in a symmetric oligopoly market. A clearing price equal to a Pigouvian tax will endogenously result in the permits auction market.*

Proposition 1 state that if combined with output refund, an ad valorem tax can be used as a policy instrument to address the underproduction caused by imperfect competition. In order to determine such an ad valorem tax, regulators need to know the information of the demand elasticity and the first best output level of this industry. For the demand elasticity, it can be estimated by some empirical approach. As for the first best output level of this industry, regulators need to know the cost information from firms in order to determine the first best output level. But if the abatement cost and the production cost for firms are separable unlike our assumption, regulators only need to know the firm's production cost function. The abatement cost will not be necessary for regulators to know. The section above gives an analysis suited to a short run situation. In the short run, as we know, the investment for abatement technology is fixed and firms cannot make any adjustment for such investment. But over the long run, firms have to take the abatement investment into their consideration together with the output and emissions level.

4. An introduction of abatement technology investment

In this section, we will introduce abatement investment into our model. We define k_i as the firms' investment for abatement technology and let $K = \sum_{i=1}^{n} k_i$ denote aggregate abatement investment of the industry. Therefore the firm's cost function can be written as $C^i(q^i, e^i, k_i)$ after introducing an abatement investment. We assume the cost function is convex with respect to the investment $C^i_{kk}(q^i, e^i, k_i) > 0$. We also assume $C^i_k(q^i, e^i, k_i) < 0$, $C^i_{qk}(q^i, e^i, k_i) < 0$, $-C^i_{ek}(q^i, e^i, k_i) < 0$. We let r denote the market price for the investment capital. In this case, the firms need to choose their optimal investment level besides the output and the emissions that they desire. Considering the abatement investment cost, regulator's objective function becomes:

$$MaxW(q,e,k) = \int_0^Q P(z)dz - \sum_{i=1}^{n} C^i(q^i, e^i) - D(E) - \sum_{i=1}^{n} rk_i$$

The first order equilibrium conditions with respect to q^*i, e^*i and k_i^* are given by

$$P(Q) - C^i_q(q^i, e^i, k_i) = 0$$

$$-C_e^i(q^i, e^i, k_i) - D^{'}(E) = 0$$

$$-C_k^i(q^i, e^i, k_i) - r = 0$$

In order to encourage firms to invest in abatement technology, we split the original refunds into two sections, one section would be refunded based on the output shares and the other would be refunded based on the abatement investment shares. We let λ denote the proportion of output refund and $1-\lambda$ denote the proportion of investment refund. Other than picking an optimal ad valorem tax φ, regulators need to determine a best ratio λ to induce firms to produce, abate and invest in the social optimal level. Integrate the ad valorem tax, the abatement investment and the splitting ratio into firm's objective profit function,

$$\underset{e^i}{Max}\,\pi^i = (1-\varphi)P(Q)\cdot q^i - C^i(q^i, e^i, k_i) - rk_i - \tau\cdot e^i + \lambda\frac{q^i}{Q}\tau E + (1-\lambda)\frac{k_i}{K}\tau E$$

$$st.\ e^i \leq E - \sum_{\substack{j=1\\ j\neq i}}^{n} e^j(\tau)$$

Similarly the first order conditions in a symmetric situation can be written

$$(1-\varphi)P(Q) + (1-\varphi)P^{'}(Q)q - C_q(q,e,k) + \lambda\tau E\frac{n-1}{n^2 q} = 0$$

$$(n-1)C_e(q,e,k)e_\tau - e(\tau) + (n-1)\tau e_\tau + \lambda\frac{q}{Q}E + (1-\lambda)\frac{k}{K}E = 0$$

$$-C_k(q,e,k) - r + (1-\lambda)\tau E\frac{K-k}{K^2} = 0$$

Substitute the welfare maximizing equilibrium conditions into the above equations, we get the following simplifications.

$$-\varphi P(Q) + (1-\varphi)P^{'}(Q)q + \lambda\tau E\frac{n-1}{n^2 q} = 0 \tag{12}$$

$$-(n-1)D^{'}(E)e_\tau - e(\tau) + (n-1)\tau e_\tau + \lambda\frac{q}{Q}E + (1-\lambda)\frac{k}{K}E = 0 \tag{13}$$

$$(1-\lambda)\tau E\frac{K-k}{K^2} = 0 \tag{14}$$

From equation (14), we can confirm $\lambda = 1$ since the rest part $\tau E(K-k)/K^2$ definitely does not equal to zero from our assumption, which means, in order to induce the first best investment, regulator should refund the auction revenues entirely based on firm's output shares. Substitute $\lambda = 1$ into equation (13), a clearing price equal to Pigouvian tax would endogenously result since $qE/Q = E/n = e$ is tenable under a symmetric situation, that is $\tau = D^{'}(E)$. Note that equation (13) and equation (14) actually indicate that the output based refund alone can bear the full burden for leading firms to achieve the social optimal level in abatement and the relevant investment for abatement. Further substitute the best splitting ratio $\lambda = 1$ and the clearing price $\tau = D^{'}(E)$ into equation (12), the optimal ad valorem tax can be expressed as

$$\varphi = \frac{\frac{1}{\eta} + D^{'}(E)\frac{E}{n}\frac{n-1}{Q^* P(Q^*)}}{1+\frac{1}{\eta}}$$

We get the same expression for ad valorem tax φ as the one we derive in the situation of not considering the abatement investment. The function of ad valorem tax here is still the same as what we discussed in the former section. Regulator just needs to keep the same ad valorem tax under the output refund scheme over the long run in order to stimulate firms to invest, to abate and to produce at the social efficient level. It doesn't require regulator to learn the investment information of firms' abatement.

5. Conclusion

In this paper, we first demonstrate that market failure problems will exist in both the permit market and the imperfect product market if regulators implement a uniform price auction to allocate the initial permits. Then we show that combining the classic output refund with an ad valorem tax that we derived can restore these market failures and lead firm to achieve the social optimal level in terms of production and abatement. Further, we take firms abatement investment into the consideration. We find that this scheme still works well on inducing firms to invest in abatement at an efficient level.

Theoretically auction has been widely recommended as a good way to allocate the initial permits, either for the following emissions trading among firms or for working alone as a price instrument to regulate the pollution. But when it comes to put auction into practice, it may suffer from the resistances of polluting firms and they may threat to relocate or go out of business. Combining the refund with an auction may relax the resistance to some extent.

Multiple further researches can be extended on this issue. First, we can relax the assumption of a fixed number of firms in the market and take an endogenous entry into the consideration. We can examine whether this refunding scheme could attract more entries into the industry and what is the optimal number of firms for the industry over a long run. Second, in this paper we didn't put the secondary market into our consideration. But actually when the auction is regarded as the first step to allocate the initial permits before the trading in the secondary market, there may exist some kind of interactions between these two markets. Therefore, further research can be extended based on such interactions under the auction refund scheme.

References

Ausubel, Lawrence and Peter Cramton,.2002. Demand Reduction and Inefficiency in Multi-unit Auctions. working paper, University of Maryland.

Back, K.and Zender, J. F.,1993. Auctions of Divisible Goods: On the Rationale for the Treasury Experiment. The Review of Financial Studies, 1993, 6, No. 4, 733-764.

Back, K.and Zender, J. F.,2001. Auctions of Divisible Goods with Endogenous Supply. Economics Letters, 73, 29-34.

Barnett, A.H., 1980. The Pigouvian tax rule under monopoly. American Economic Review 70, 1037-1041.

Buchanan, J.M., 1969. External diseconomies, corrective taxes, and market structure. American Economic Review 59, 174-177.

Gersbach H, Requate T., 2004. Emission taxes and optimal refunding schemes. Journal of Public Economics 88, 713-725.

Kremer, I., and K. G. Nyborg., 2004. Underpricing and market power in uniform price auctions. Review of Financial Studies 17, 849-877.

Levin, D., 1985. Taxation within Cournot oligopoly. Journal of Public Economics 27, 281-290.

LiCalzi, Marco and Pavan, Alessandro., 2005. Titling the supply schedule to enhance competition in uniform price auctions. European Economic Review, Vol. 49 (1), 227-250.

Shaffer, S., 1995. Optimal linear taxation of polluting oligopolists. Journal of Regulatory Economics, 7, 85-100.

Simpson, R.D., 1995. Optimal pollution taxes in Cournot duopoly. Environmental and Resource Economics 9, 359-396.

Wilson, R., 1979. Auctions of Shares. Quarterly Journal of Economics, 93,675-698.

Impact Analysis on Emission Trading for Water Pollution Control in Ise Bay Basin
- Combined Use of Baseline and Credit Program -

Takaaki OKUDA

EcoTopia Science Institute, Nagoya University, Nagoya, 464-8603, Japan
(e-mail: okuda@nagoya-u.jp)

Abstract. The introduction of an emissions trading is being considered as a way to reduce the pollution load in closed water areas at a minimal cost to society. In this study, a CGE (computable general equilibrium) model was developed for impact assessment of emissions trading. The model was applied to the Ise Bay Basin and a quantitative analysis was performed to determine the effect of introducing an emissions trading. The analysis found that 1) when emissions trading was conducted by a cap and trade program for the mining and manufacturing industries alone, the water pollution load was reduced in the Yokkaichi and Gifu regions, with the costs borne by regions within Aichi Prefecture; 2) when this cap and trade program was combined with a baseline and credit program for the agriculture, forestry and fisheries industries, the water pollution load was reduced in regions within Gifu Prefecture and in the Toyohashi and Ise regions, with the costs borne by Nagoya City and the Toyota and Yokkaichi regions; and 3) with the latter method, the impact on the region was moderated.

JEL classification: Q53, Q58, R15

Key words: domestic tradable permits, water pollution control, CGE model

1. Introduction

With the industrialization and urbanization in the 20th century, water environment problems in Japan have gradually become more severe, and in recent years the pollution of the water in inland bays, inland seas, lakes and other closed water areas has become a serious problem facing society. In Tokyo Bay, Osaka Bay, Ise Bay and other areas in particular that are near metropolitan regions as major pollutant sources, total pollutant load regulations that regulate the total pollutant load flowing into the bay have been introduced in an effort to improve water quality. Despite these efforts, however, environmental standards in these closed water areas still have not been achieved.

As a result of this situation, the water pollution load has been reduced from factories in specified regions that are subject to total pollutant load regulations, but effective measures have not been implemented for the agricultural sector and other sectors that are not covered by total pollutant load regulations. In sectors such as the agricultural sector, the pollutant load source is distributed over a wide area, and although the pollutant load per unit area is small, the total emissions add up to a considerable amount. To improve water quality in closed water areas, new measures are needed for these sectors.

Accordingly, the introduction of emissions trading can be seen as a means for achieving a reduction in the pollution load in closed water area regions at a minimal cost to society. In Japan, emissions trading in closed water areas has been studied by the sewer system sector, primarily the Ministry of Land, Infrastructure, Transport and Tourism. However, in sewer system construction, a region-specific Sewer System Construction Plan is prepared and then the project is implemented with considerable government subsidies. For this reason, there is little incentive for local governments to implement emissions trading in cooperation with one another. Accordingly, it is thought to be more effective to introduce emissions trading by means of a cap and trade approach, one that targets factories within specified regions that are subject to emission controls under the total pollutant load regulations, and to combine this with offsets created through a baseline and credit program for entities such as the agricultural sector that are not subject to total pollutant load regulations.

In this study, a quantitative model was developed for impact assessment of emissions trading conducted to reduce the water pollution load in closed water areas. This model was used to perform a quantitative analysis of this impact. Section 2 will discuss previous related studies on the topic of emissions trading conducted to reduce water pollution load. Section 3 will discuss the specific content of the emissions trading system analyzed in this study and the perspective for the impact assessment. Section 4 will present the quantitative model used to evaluate the effect of emissions trading. Section 5 will present the results of parameter estimations of this model for the Ise Bay Basin. Section 6 will report the results of the use of this model to conduct a quantitative analysis of the effect of introducing emissions trading in the Ise Bay Basin.

2. Previous studies

(1) Emissions trading for water pollution control

Many studies have been conducted on emissions trading for the purpose of reducing water pollution load. Among other things, these studies have pointed out that this would enable emissions reduction targets to be achieved at a minimal cost to society, that emissions trading would be more acceptable than levying surcharges, and that monitoring costs would rise as the number of transaction entities increased. There are also examples of actual emissions trading having been conducted in several countries including the United States (OECD (1999) and DBJ (2003)). For example, in the Tar-Pamlico River Basin in North Carolina, the North Carolina Department of Environment and Natural Resources imposed total pollutant load regulations on nitrogen and phosphorus, and sewage treatment plants and factories in the basin became members of the Tar-Pamlico Basin Association and engaged in emissions trading with other members. Moreover, the Association actively provided support for efforts on the part of farming households in the river basin to reduce nitrogen and phosphorus emissions. Members purchased the portion of nitrogen and phosphorus emissions reductions in the agricultural sector as credits to achieve their emissions reduction obligations. As a result of this emissions trading, it was reported that nitrogen and phosphorus emissions in the Tar-Pamlico River Basin were reduced by 28% (Anderson et al (1997), Nishizawa (2000) and Nishizawa (2001)).

(2) Emissions trading in Japan

Several studies have been conducted regarding the possibility of introducing such emissions trading systems in Japan. For example, the Ministry of Land, Infrastructure, Transport and Tourism was conducting a detailed study regarding the possibility of introducing emissions trading in the sewer system sector (MLIT (2003) and MLIT (2005)). Moreover, Ishida et al (2005) are conducting a quantitative analysis, using a bottom up model, to determine the degree of impact that can be anticipated if an emissions trading system were implemented for the sewer system sector in the Tokyo metropolitan area. Based on these studies, the Ministry of Land, Infrastructure, Transport and Tourism revised the Sewerage Service Act in 2005 to enable emissions trading among local governments. However, in Japan, sewer systems are constructed by first establishing a (river basin-specific) Sewer System Construction Plan and then implementing the construction with abundant government subsidies. For this reason, at the stage of budget allocation for public projects, a study is naturally conducted to determine the most efficient way to construct the sewer system, and so there is little incentive for local governments to use emissions trading to reduce the water pollution load. As a result, up to now there have been no examples of this type of emissions trading having been implemented among local governments in Japan.

(3) Purpose of this study

On the other hand, as discussed in Section 1, total pollutant load regulations have been instituted in Japan, primarily by the Ministry of the Environment. Under these regulations, factories in specified regions are subject to certain controls. Moreover, a considerable water pollution load is emitted from the agricultural and other sectors, which are not subject to these total pollutant load regulations, and finding a way to reduce emissions in these sectors has become a serious issue. Accordingly, this study proposes that emissions trading using a cap and trade program be conducted for the factories in specified areas that are currently subject to total pollutant load regulations, and in addition that emissions trading using a benchmarks and credits program be implemented for the agricultural sector and other entities that are not subject to total pollutant load regulations. A prior assessment was also conducted to determine the effect on the target area of introducing these systems.

3. Perspective for analysis

(1) Cap and trade program

Up to now, certain restrictions on water pollution load emissions have been imposed on factories in specified regions that are subject to total pollutant load regulations. To achieve additional improvements in water quality, these factories will have to reduce emissions further. For this reason, reductions must be actively promoted, beginning with the factories that are capable of reducing water pollution load, and a mechanism capable of achieving these objectives at a minimal cost to society must be introduced. Accordingly, this study will consider the implementation of a cap and trade program for the entities that are subject to such total pollutant load regulations (Fig. 1). In a cap and trade program, emissions reduction targets are established for the target region as a whole, and the water pollution load that can be emitted while still achieving the targets is established in the form of emissions credits. Then these emissions credits are allocated in accordance with the water pollution load of each factory, and factories are required to keep their water pollution load to within the scope of the allocated emissions credits. In the event that a factory achieves reductions in water pollution load that are even greater than its allocated emissions credits, it may sell the remaining emissions credits in the emissions trading market. Conversely, if a factory purchases emissions credits from the emissions trading market, it may emit a water pollution load that is even greater than its allocated emissions credits. The price of emissions credits on the emissions trading market is determined so as to achieve a balance in emissions credit supply and demand.

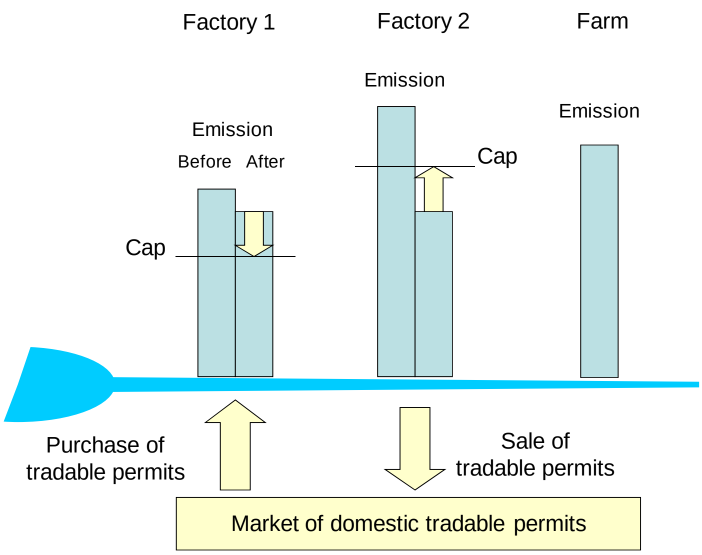


Fig. 1 Cap and trade program

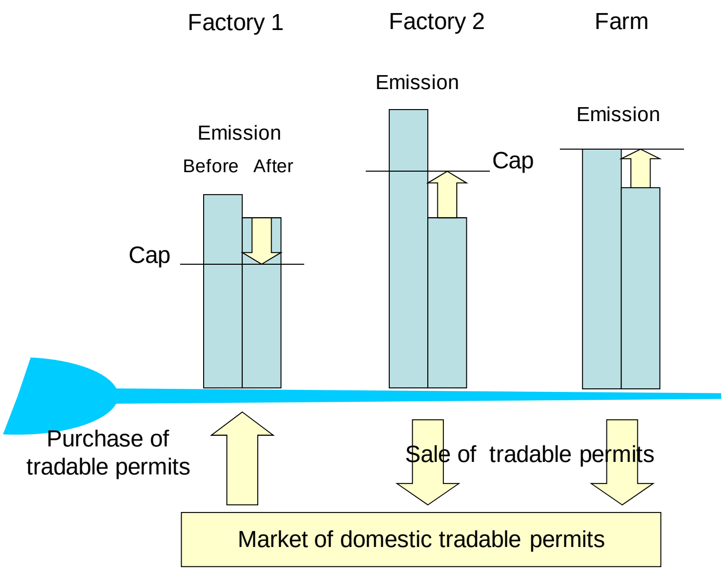


Fig. 2 Combined use of baseline and credit program

(2) Combined use of baseline and credit program

On the other hand, the agricultural and other sectors have not been subject to total pollutant load regulations up to now. Accordingly, as a practical matter, is thought that it will be difficult to convince these sectors to participate in a cap and trade emissions trading program that obligates them to reduce emissions. However, as these sectors account for a large proportion of the total water pollution load that is emitted, providing incentives for these sectors to reduce water pollution load will be crucial to the success of the policy. Accordingly, this study will consider the implementation of combined use of a baseline and credit program for the agricultural sector and other entities that are not subject to total pollutant load regulations (Fig. 2). For these sectors, the current level of water pollution load emissions will be used as a baseline. If the water pollution load is reduced below this level, credits equivalent to that amount will be provided, and the entity may sell these credits in the emissions trading market to gain income. This will make it possible for even sectors that have not been subject to total pollutant load regulations to obtain a new source of income by reducing their water pollutant load, providing them with a certain incentive to reduce their water pollutant load.

(3) Impact assessment perspective

At this point, let us consider the impact that would be produced in the target regions if emissions trading were implemented using these two programs. Whereas many of the industrial sectors are located in urban areas, many agricultural sectors are located in the surrounding rural areas. For this reason, if the emissions trading were implemented, there are expected to be great differences in the impact in urban and rural areas, and it is necessary to evaluate who would reduce the water pollution load in each of these areas.

Moreover, if emissions trading were introduced, who would bear the costs of the reduction in water pollution load? Obviously the direct cost burden is borne by the producers who purchase emissions credits from the emissions trading market. However, if these producers pass on the cost of water pollution load reductions in the prices of their products, the impact will extend to even more entities, and ultimately the cost will be borne by the consumers in each region. There are thought to be great differences between urban and rural areas in terms of this cost burden problem as well, and this study will attempt to identify such regional differences in terms of impact.

4. Development of an impact assessment model

(1) Basic concept for the model development

In order to assess the effect of the introduction of emissions trading using these two programs on regional economic activities, for this study an impact assessment model was developed based on a CGE (computable general equilibrium) model. The CGE model is a quantitative models with endogenous markets based on general equilibrium theory (Shoven et al (1992) and Hosoe et al (2004)). The CGE model can handle not only existing markets for products, production factors etc. but also virtual markets that do not actually exist such as the emissions trading market. Moreover, when such markets are established, the impact is expected to extend not only to the economic entities that participate directly in the market but also to many other economic entities, through other markets in which those economic entities trade. The CGE model is capable of making a comprehensive determination of the impact that introducing such new markets will have on economic activities in the target region through all related markets.

(2) Production functions for industrial sector

Fig. 3 shows the industrial functions assumed to exist for the industrial sector of industry j in region s. With regard to intermediate input, the goods produced within each region are combined using the constant elasticity of substitution (CES) production function, and those composite goods and the imported goods that are produced in other regions are also combined using the CES production function. With regard to primary input, labor and capital are combined using the Cobb-Douglas production function, and the composite goods and emissions credits are combined using the Leontief production function. Furthermore, it is assumed that the intermediate input and primary input are combined using the Leontief production function.

(3) Profit of industrial sector

The emissions credits allocated to the industrial sector for industry j in region s are represented by $\overline{E}(s,j)$. If the emissions $E(s,j)$ of the industrial sector are greater than the allocated emissions credits, the insufficiency in emissions credits must be purchased from the emissions trading market. For this reason, if the price of the emissions credits is P_E, the profit of the industrial sector $\pi(s,j)$ will be as follows.

$$\pi(s,j) = \overline{\pi}(s,j) - P_E \cdot \left\{E(s,j) - \overline{E}(s,j)\right\} \tag{1}$$

where $\overline{\pi}(s, j)$: revenue minus costs other than those from emissions trading

If the emissions of the industrial sector are lower than the allocated emissions credits, the excess emissions credits may be sold on the emissions trading market. In such cases, the profit of the production sector is as follows.

$$\pi(s, j) = \overline{\pi}(s, j) + P_E \cdot \{\overline{E}(s, j) - E(s, j)\} \tag{2}$$

Ultimately the profit of the production sector is as follows regardless of whether emissions credits are purchased or sold.

$$\pi(s, j) = \overline{\pi}(s, j) + P_E \cdot \overline{E}(s, j) - P_E E(s, j) \tag{3}$$

In other words, the allocated emissions credits can be considered to have all been sold, so the emissions credits needed for water pollution load emissions must be purchased from the market. Moreover, if the nested CES production function discussed in (2) is assumed, the marginal costs and average costs will be equal. For this reason, the price of products is determined using the average cost, and the following profits are produced for the industrial sector.

$$\pi(s, j) = P_E \cdot \overline{E}(s, j) \tag{4}$$

In this study, the profit of the industrial sector is assumed to be redistributed in the final demand sector for the same region.

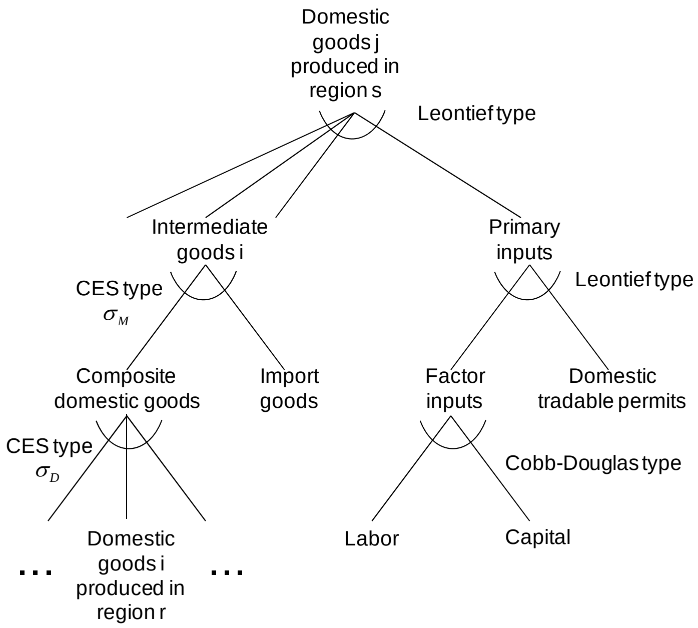


Fig. 3 Production functions

(4) Market conditions

In the emissions trading market, the price of emissions credits is determined in the level that supply and demand will be in balance. In this process, emissions credit demand is the sum total of the emissions credits needed by each production sector $E(s, j)$, and emissions credit supply is the sum total of the emissions credits allocated to each production sector $\overline{E}(s, j)$. Accordingly, when these two are in equilibrium, the following equation is satisfied.

$$\sum_s \sum_j \overline{E}(j,s) = \sum_s \sum_j E(j,s) \tag{5}$$

(5) Initial allocation of emissions credits

The following emissions credits are allocated in the industrial sectors that conduct emissions trading in a cap and trade program.

$$\overline{E}(j,s) = (1-\alpha) \cdot \hat{E}(j,s) \tag{6}$$

where $\hat{E}(j,s)$ is current water pollution load emissions, α is ratio of reduction in water pollution load established as a policy objective for the entire target region

For industrial sectors conducting emissions trading in a baseline and credit program, emissions credits that are equivalent to the current level of emissions are allocated.

$$\overline{E}(j,s) = \hat{E}(j,s) \tag{7}$$

(6) Effect of emissions trading

Fig. 4 shows how the effect of emissions trading is analyzed using the CGE model. If a water pollution load is directly emitted as in the case of industrial sector A, the emissions credits must be purchased from the market at a certain price. Industrial sector A makes an effort to produce goods while reducing water pollution load to the greatest degree possible, but as there are limits to the extent to which this is possible, production costs increase, and this increase must be passed on in the form of an increase in the price of the goods that are produced. If, as in the case of industrial sector B, the industry does not merely emit water pollution load but also purchases intermediate goods in the form of raw materials from industrial sector A, not only must the water pollution load be reduced but at the same time the input from these intermediate goods must be reduced. If, as in the case of industrial sector C, the industry does not directly emit water pollution load but it purchases intermediate goods from industrial sector B, that input must also be reduced while conducting production activities.

In this way, when emissions trading is introduced, the price of the goods that are produced increases overall as a result of inter-industry relationships. On the other hand, the profit on the sale of emissions trading is reallocated from the industrial sector to the final demand sector. These changes in price and income change the consumption in the final demand sector, and this also changes the utility that can be achieved. Moreover, if the consumption in the final demand sector changes, industrial sector C must also change its production. In addition, as industrial sector C will reduce the input of intermediate goods because of the significant increase in the price of these goods, industrial sector B will have to change its production. This change in production will be needed in upstream industrial sectors A and D as well, and the effect will have wide repercussions as a result of inter-industry relationships.

Next, let us consider how the effect of emissions trading through these two systems is analyzed using the applied general equilibrium model. When emissions trading using a cap and trade system has been introduced, the industrial sectors that participate in emissions trading will be limited. For this reason, even the production sectors with high marginal abatement costs will have to reduce their water pollution load, and the price of emissions credits is expected to become relatively high. In contrast, when a benchmarks and credits system is used as well, industrial sectors with relatively low marginal abatement costs such as the agriculture, forestry and fisheries industries will also be included in emissions trading, so the price of emissions credits is expected to become low. If the price of emissions credits can be kept low, it is thought that the aforementioned repercussions resulting from inter-industry relationships will be relatively minor.

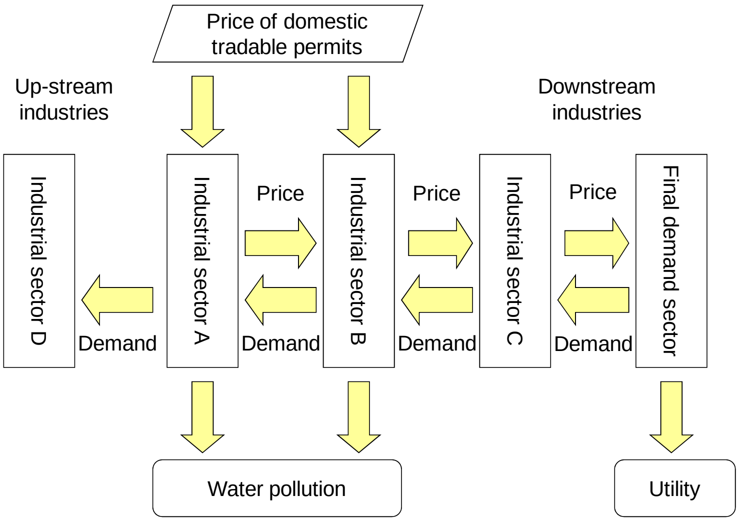


Fig. 4 Effect of emissions trading

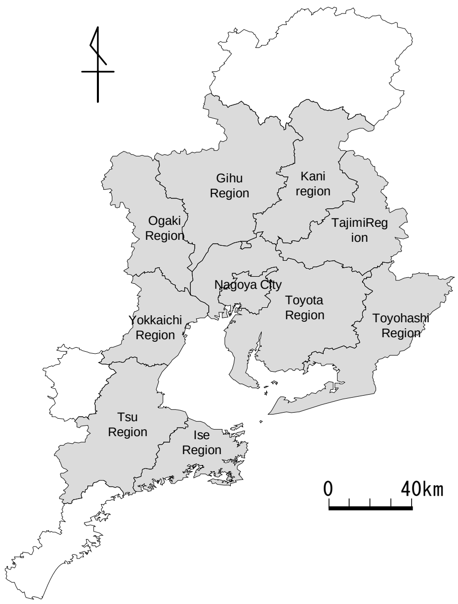


Fig. 5 Target region

Table 1 Industrial divisions

3 sectors	10 sectors	32 sectors
Agriculture	Agriculture	1)Agriculture, forestry and fisheries
Manufacturing	Mining	2)Mining
	Food	3)Food, beverage and tobacco
	Metal	4)Iron and steel, 5)Non-ferrous metal, 6)Metal products
	Machinery	7)Ordinary machinery, 8)Electric machinery, 9)Transport equipment, 10)Other machinery
	Other manufacturing	11)Textile, 12)Pulp, paper and wooden products, 13)Chemical products, 14)Petroleum products, 15)Non-metallic mineral products, 16)Rubber products, 17)Other manufacturing
	Construction	18)Construction
	Electricity	19)Electricity and gas, 20)water supply
Services	Trade	21)Trade, 22)transportation, 23)Telephone and telecommunication
	Other services	24)Finance and Insurance, 25)Real estate, 26)Medical service, 27)Public administration, 28)Education, 29) Other public service, 30)Business service, 31)Personal service, 32)Other services

5. Creation of a model for the Ise Bay Basin

(1) Regional divisions and industrial divisions

The impact assessment model proposed in Section 4 was applied to the Ise Bay Basin and the parameters for the model were established. The Ise Bay Basin is the region from which rainfall flows into Ise Bay, extending across Aichi, Gifu and Mie Prefectures (Fig. 5). Strictly speaking, this area also includes a portion of Nagano Prefecture, but as the included portion is very small in terms of area, population and production, it was excluded from the analysis in this study. The model was developed by dividing the Ise Bay Basin into the 10 regions shown in Fig. 5 according to regional living spheres (Ministry of Construction (1993)).

In addition, as this model is based on the applied general equilibrium model, an interregional input-output table is needed for model calibration. The table estimated by Hashimoto (2003) was used as the interregional input-output table with the Ise Bay Basin separated into regional living zones. As Hashimoto estimated the interregional input-output table for 32 industrial divisions, for the purposes of this study these divisions were consolidated into 10 industrial divisions. (Table 1). In the discussion of the assessment results, these 10 industrial divisions are consolidated into three divisions as needed.

(2) Estimation of water pollution load

Next, in order to create an impact assessment model for the Ise Bay Basin, it was necessary to estimate the water pollution load for the regional divisions and industrial divisions corresponding to those in the interregional input-output table discussed in (1). For the purposes of this study, water pollution load was defined as the emissions from chemical oxygen demand (COD), total nitrogen and total phosphorus generating sources. Each of these values was estimated using the following procedure. First, primary estimates for each industry and region were derived by multiplying the basic unit of water pollution load for each industry (Japan Sewage Works Association (2001)) by the production volume for each region and each industry in the interregional input-output table.

However, the primary estimates derived in this manner do not match the emissions (for FY 1999) for each emissions source and each prefecture estimated by the Ministry of the Environment. Accordingly, the primary estimates were corrected to enable the Ministry of the Environment estimates to serve as a control total in order to produce the final water pollution load estimates.

In addition, for the purposes of this study, the emissions of total nitrogen and total phosphorus were converted to COD emissions, using the study by Ishida et al 8) as a reference (the COD conversion factors for total nitrogen and total phosphorus were 19.7 and 142.5, respectively), and the analysis was conducted for a unified water pollution load. Fig. 6 shows the size of the water pollution load from industrial sectors. As the figure shows, the regions with a large water pollution load from industrial sectors included the Toyota region (336,000 t/year), the Yokkaichi region (118,000 t/year) and the Gifu region (110,000 t/year). Each of these regions has a high proportion of emissions from the mining and manufacturing industries (55.9% for the Toyota region, 76.1% from the Yokkaichi region and 44.1% for the Gifu region). Nagoya City has a high proportion of emissions from not only the mining and manufacturing industries but also the commercial and service industries (24.2%). In addition, the regions surrounding the Ise Bay Basin have a high proportion of emissions from the agriculture, forestry and fisheries industries (44.9% for the Gifu region, 44.7% for the Ogaki region, 55.0% for the Kani region, 52.4% for the Tajimi region, 59.5% for the Toyohashi region, 52.0% for the Tsu region and 68.8% for the Ise region).

(3) Establishment of elasticity of substitution values

Furthermore, in order to determine the production functions shown in Fig. 3, it is necessary to derive the values for elasticity of substitution (σ_M and σ_D) for CES production functions. For the purposes of this study, the values (Table 2) estimated by Okuda and Hashimoto (2003) and Okuda (2006) were used. The elasticity of substitution value σ_M was derived from the values estimated by the Ministry of Economy, Trade and Industry in the interregional input-output table for the entire country. The elasticity of substitution value σ_D was derived from the interregional input-output table for Mie Prefecture. It can be seen that the elasticity of substitution value σ_D for the region was greater for all industries.

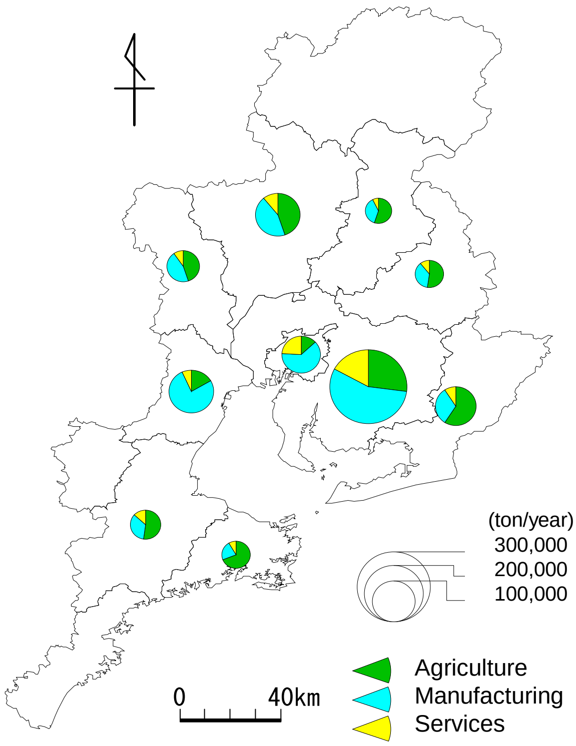


Fig. 6 Water pollution load from production sectors

Table 2 Establishment of elasticity of substitution values

Sector	σ_M	σ_D
Agriculture	2.4	4.8
Mining	3.1	4.7
Food	2.3	4.0
Metal	2.1	3.4
Machinery	1.3	3.9
Other Manufacturing	2.0	4.0
Construction	—	—
Electricity	6.5	8.8
Trade	2.7	4.7
Other services	3.9	6.5

6. Impact assessment for emissions trading in Ise Bay Basin

(1) Scenario establishment

The model created in Section 5 was used to make a quantitative assessment of the impact that would be produced on the target region in the event that emissions trading were implemented in the Ise Bay Basin. For this assessment, the policy objective was a 10% reduction in the water pollution load emitted from the mining and manufacturing industries for the Ise Bay Basin as a whole, and emissions trading was introduced as a policy measure for achieving this objective. The following two scenarios were established according to the industries involved in emissions trading.

Scenario 1

In this scenario, the current water pollution load emitted by the mining and manufacturing industries must be reduced by 10%, and emissions credits are allocated in accordance with the water pollution load that can be emitted. Industries whose water pollution load exceeds the allocated emissions credits are obligated to purchase emissions credits from the emissions trading market. Conversely, surplus emissions credits produced by reduction in water pollution load may be sold on the emissions trading market.

Scenario 2

In Scenario 2, the agriculture, forestry and fisheries industries are added to the emissions trading considered in Scenario 1. However, the agriculture, forestry and fisheries industries are not obligated to reduce their water pollution load. If they do so, they are provided with credits corresponding to the reduction, and they may sell these credits on the emissions trading market. In this case, the reduction in water pollution load for the Ise Bay Basin overall is the same as in Scenario 1.

(2) Reduction of water pollution load

Fig. 7 shows the rate of reduction in water pollution load as a result of emissions trading for each region. When emissions trading was conducted for the mining and manufacturing industries only (Scenario 1), progressive reductions were achieved in the water pollution load for the metal, mining and other manufacturing industries as well as manufacturing for public works, etc. For example, reductions in water pollution load of 9.5% for the Yokkaichi region and 4.8% for the Gifu region were achieved. These are both areas with a relatively high concentration of these industries. When emissions trading was allowed for the agriculture, forestry and fisheries industries as well (Scenario 2), a 12.8% reduction in water pollution load was achieved for the agriculture, forestry and fisheries industries overall in the target region. As a result, the water pollution load was reduced in the regions within Gifu Prefecture with a high level of production in the agriculture, forestry and fisheries industries (9.7% for the Gifu region, 9.6% for the Ogaki region, 11.7% for the Kani region, and 11.0% for the Tajimi region). Moreover, progressive reductions in water pollution load were also achieved in other regions, such as 5.3% for the Toyohashi region, 4.9% for the Tsu region and 6.2% for the Ise region. In other words, when the agriculture, forestry and fisheries industries were included in emissions trading, the water pollution load was reduced in the surrounding areas in the Ise Bay Basin.

(3) Cost burden for reduction of water pollution load

Fig. 8 shows the amount of emissions credits purchased by industries in each region under the emissions trading system. The purchase amounts of emissions credits are represented by the size of the cost burden for reducing water pollution load in the Ise Bay Basin. For the scenario in which emissions trading is conducted for the mining and manufacturing industries alone (Scenario 1), the market price for emissions credits was US$ 25.1 / kg. In this scenario, all of the regions in Aichi Prefecture purchased emissions credits. The Toyota region purchased the largest emissions credit amount at US$ 129 million, followed by the Toyohashi region (US$ 24.6 million / year) and Nagoya

City (1.83 billion / year). Conversely, all of the regions in Gifu Prefecture and Mie Prefecture sold emissions credits, and the amount of emissions credits sold was particularly great in the case of the Yokkaichi region (US$ 76.7 million / year) and the regions in the Gifu region (US$ 49.9 million / year). In contrast, when the agriculture, forestry and fisheries industries were also allowed to conduct emissions trading (Scenario 2), the market price for emissions credits dropped to US$ 1.97 / kg. In this scenario, the Yokkaichi region, which has a low level of production in the agriculture, forestry and fisheries industries, purchased emissions credits, while conversely the Toyohashi region which has a high level of production in these industries sold emissions credits. Overall, however, the amounts for the purchase and sale of emissions credits were lower than in Scenario 1. This is because of the progressive reduction in water pollution load in the agriculture, forestry and fisheries industries, as a result of which the price of the emissions credits dropped.

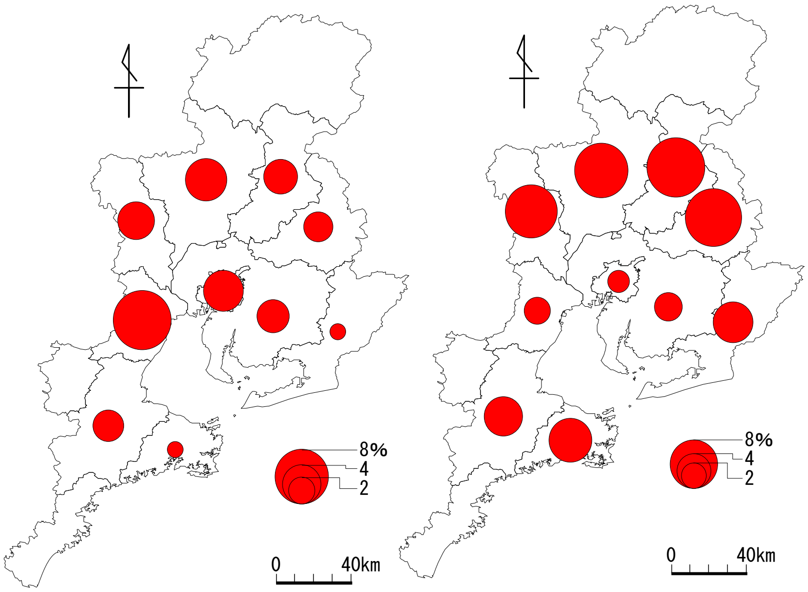


Fig. 7　Reduction rate for water pollution load

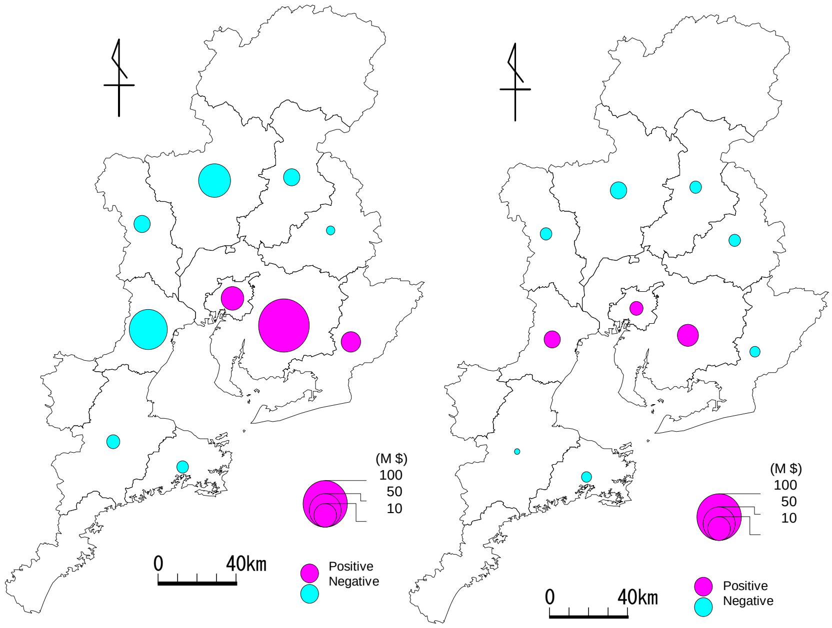


Fig. 8 Emission credit purchase amounts

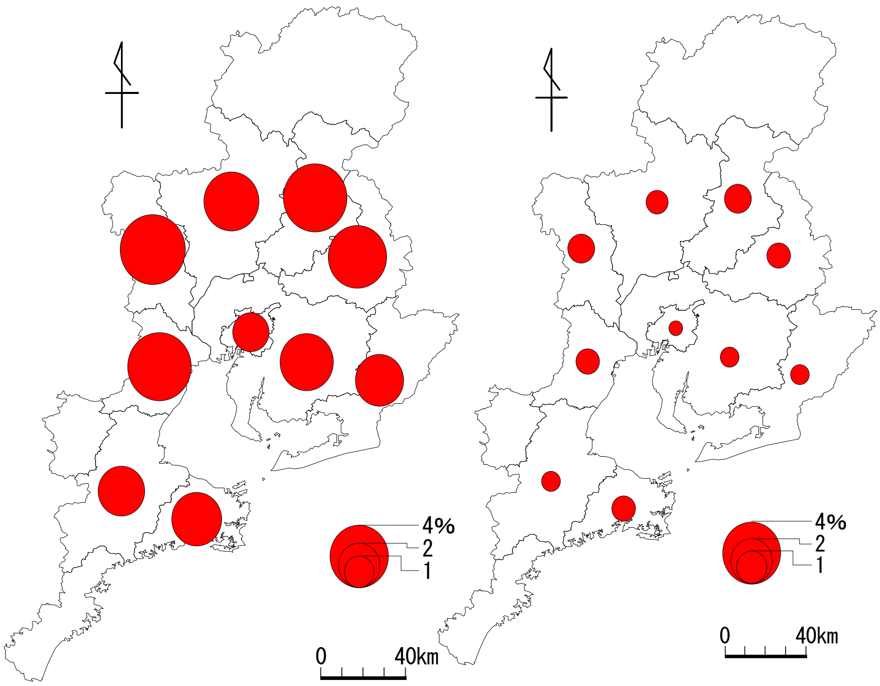


Fig. 9 Rate of decrease in utility

(4) Change in utility due to reduction of water pollution load

Fig. 9 shows the degree to which utility in the final demand sectors was reduced as a result of reduced water pollution load due to emissions trading. For the scenario in which emissions trading was conducted only for the mining and manufacturing industries (Scenario 1), utility in the final demand sectors was reduced in the Ise Bay Basin overall (for example, by 5.0% in the Ogaki region, 4.7% in the Kani region and 4.7% in the Yokkaichi region). In this scenario, a new source of revenue through the sale of emissions credits was obtained in the regions in which it was easy to reduce the water pollution load, but the increase in the price of goods produced as a result of the introduction of emissions trading caused utility to decrease in all regions. In contrast, when the agriculture, forestry and fisheries industries were also allowed to conduct emissions trading (Scenario 2), it was possible to prevent a decrease in utility in all regions (for example, the decrease was only 0.8% for the Ogaki and Kani regions). As the water pollution load is comparatively great in the agriculture, forestry and fisheries industries, the ability to reduce the water pollution load in these industries means the effect on other industries is comparatively mild and it is possible to prevent a decrease in utility.

7. Conclusion

This study has considered emissions trading systems as a means of reducing the water pollution load in closed water areas at a minimal cost to society. The combination of two programs was proposed: 1) the introduction of emissions trading using a cap and trade program for entities that are already subject to total pollutant load regulations, and 2) participation in emissions trading using a baseline and credit program for entities that are not subject to total pollutant load regulations. A quantitative model was also developed for the impact assessment of introducing these programs. The distinguishing characteristic of this impact assessment model was that a new market called an emissions trading market was incorporated into a CGE (computable general equilibrium) model with endogenous markets, enabling a comprehensive determination of the effect of emissions trading. In addition, a specific impact assessment model was prepared for the Ise Bay Basin in order to make a quantitative analysis of the impact of the emissions trading in the Ise Bay Basin.

The analysis revealed the following: 1) when emissions trading was conducted using a cap and trade program for only the mining and manufacturing industries in the Ise Bay

Basin, the water pollution load was reduced in the Yokkaichi and Gifu regions, with the cost being borne by regions in Aichi Prefecture, 2) when the agriculture, forestry and fisheries industries were also allowed to sell credits created through a baseline and credit program, the water pollution load was reduced in the regions of Gifu Prefecture as well as in the Toyohashi and Ise regions, etc., with the costs being borne by Nagoya City and the Toyota and Yokkaichi regions, and 3) a comparison of these two scenarios revealed that the latter had less of an effect on utility in the final demand sectors.

Future study is needed with regard to the following: 1) estimation of more precise production functions from the input-output data for industries in the Ise Bay Basin, 2) impact assessments using more detailed data for industrial divisions and regional divisions, and 3) evaluation of the effect of sewer construction and other public works projects as well.

Appendix CGE model

(1) Variables

1) Suffixes

i	Industry i (output)
j	Industry j (input)
r	Region r (output)
s	Region s (input)

2) Price variables

Production sectors

$P_X(j,s)$	Price of domestic goods
$P_V(j,s)$	Price of primary inputs
$P_F(j,s)$	Price of composite goods between labor and capital

Trade sectors

$P_Z(i,s)$	Price of composite consumption goods
$P_D(i,s)$	Price of composite domestic goods

Others

$P_M(i)$	Price of regional import goods
P_E	Price of domestic tradable permits
$P_L(s)$	Price of labor
P_K	Price of capital

3) Quantity variables

Production sectors

$X(j,s)$	Production of domestic goods
$Z_A(i,j,s)$	Input of intermediate goods
$V(j,s)$	Input of composite factor goods
$F(j,s)$	Input of composite goods between labor and capital
$E(j,s)$	Input of domestic tradable permits
$L(j,s)$	Input of labor
$K(j,s)$	Input of capital

Trade sectors

$Z(i,s)$	Production of composite consumption goods
$D(i,s)$	Input of composite domestic goods
$M(i,s)$	Input of regional import goods
$X_B(i,r,s)$	Input of domestic goods

Final demand sectors

$Z_C(i,s)$	Final demand

Regional export

$X_O(i,r)$	Regional export

Others

$\overline{L}(s)$	Supply of labor
$\overline{K}(s)$	Supply of capital
$\overline{E}(s,j)$	Primary allocation of domestic tradable permits

4) Value variables

$Y(s)$	Income
O	Regional export
$\pi(j,s)$	Profit of production

5) Parameters

Production sectors

$\beta_A(i,j,s)$	Coefficient of intermediate input
$\beta_V(j,s)$	Coefficient of primary input
$\beta_F(j,s)$	Coefficient of composite input between labor and capital
$\beta_E(j,s)$	Coefficient of emission
$\sigma_F(j,s)$	Elasticity of substitution between labor and capital
$\beta_L(j,s)$	Scale parameter of labor
$\beta_K(j,s)$	Scale parameter of capital

Trade sectors

$\sigma_M(i)$	Elasticity of substitution between composite domestic goods and import goods
$\beta_D(i,s)$	Scale parameter of composite domestic goods
$\beta_M(i,s)$	Scale parameter of import goods
$\sigma_D(i)$	Elasticity of substitution of domestic goods
$\beta_B(i,r,s)$	Scale parameter of domestic goods

Final demand sectors

$\beta_C(i,s)$	Shear parameter of composite consumption goods

Exports

$\beta_O(i,r)$	Shear parameter of domestic goods

(2) Equations

1) Production sectors

$$Z_A(i,j,s) = \beta_A(i,j,s)\cdot X(j,s) \tag{A1}$$

$$V(j,s) = \beta_V(j,s)\cdot X(j,s) \tag{A2}$$

$$F(j,s) = \beta_F(j,s)\cdot V(j,s) \tag{A3}$$

$$E(j,s) = \beta_E(j,s)\cdot V(j,s) \tag{A4}$$

$$L(j,s) = \beta_L(j,s)\cdot\left(\frac{P_L(s)}{P_F(j,s)}\right)^{-\sigma_F(j)}\cdot F(j,s) \tag{A5}$$

$$K(j,s) = \beta_K(j,s)\cdot\left(\frac{P_K}{P_F(j,s)}\right)^{-\sigma_F(j)}\cdot F(j,s) \tag{A6}$$

$$P_X(j,s)\cdot X(j,s) = \sum_i P_Z(i,s)\cdot Z_A(i,j,s) + P_V(j,s)\cdot V(j,s) \tag{A7}$$

$$P_V(j,s)\cdot V(j,s) = P_F(j,s)\cdot F(j,s) + P_E\cdot E(j,s) \tag{A8}$$

$$P_F(j,s)\cdot F(j,s) = P_L(s)\cdot L(j,s) + P_K\cdot K(j,s) \tag{A9}$$

$$\pi(j,s) = P_E\cdot \overline{E}(j,s) \tag{A10}$$

3) Trade sectors

$$D(i,s) = \beta_D(i,s)\cdot\left(\frac{P_D(i,s)}{P_Z(i,s)}\right)^{-\sigma_M(i)}\cdot Z(i,s) \tag{A11}$$

$$M(i,s) = \beta_M(i,s)\cdot\left(\frac{P_M(i)}{P_Z(i,s)}\right)^{-\sigma_M(i)}\cdot Z(i,s) \tag{A12}$$

$$X_B(i,r,s)=\beta_B(i,r,s)\cdot\left(\frac{P_X(i,r)}{P_D(i,s)}\right)^{-\sigma_D(i)}\cdot D(i,s) \tag{A13}$$

$$P_Z(i,s)\cdot Z(i,s)=P_D(i,s)\cdot D(i,s)+P_M(i)\cdot M(i,s) \tag{A14}$$

$$P_D(i,s)\cdot D(i,s)=\sum_r P_X(i,r)\cdot X_B(i,r,s) \tag{A15}$$

4) Final demand sectors

$$Z_C(i,s)=\beta_C(i,s)\cdot\frac{Y(s)}{P_Z(i,s)} \tag{A16}$$

5) Exports

$$X_O(i,r)=\beta_O(i,r)\cdot\frac{EX}{P_X(i,r)} \tag{A17}$$

6) Market condition of domestic goods

$$Z(i,s)=\sum_s Z_A(i,j,s)+Z_C(i,s) \tag{A18}$$

7) Market condition of composite consumption goods

$$X(i,r)=\sum_s X_B(i,r,s)+X_O(i,r) \tag{A19}$$

8) Market condition of Labor

$$\overline{L}(s)=\sum_j L(j,s) \tag{A20}$$

9) Maket condition of capital

$$\sum_s \overline{K}(s)=\sum_j\sum_s K(j,s) \tag{A21}$$

10） Market condition of domestic tradabe permits

$$\sum_s\sum_j \overline{E}(j,s)=\sum_s\sum_j E(j,s) \tag{A22}$$

11） Balace between export and import

$$O=\sum_i\sum_s P_M M(i)\cdot M(i,s) \tag{A23}$$

$$P_M(i)=\text{Constant} \tag{A24}$$

12） Income

$$Y(s)=P_L(s)\cdot\overline{L}(s)+P_R\cdot\overline{K}(s)+\sum_j \pi(j,s) \tag{A25}$$

13） Utility

$$U(s)=\prod_i C(i,s)^{\beta_C(i,s)} \tag{A26}$$

Reference

Anderson, T. L. and Hills, P. J. (1997): *Water Marketing, the Next Generation*, the Political Economy Forum, Lanham, Rowman and Littlefield Publishers.

Development Bank of Japan (2003): Emission trading for water quality management in U.S.A, *research paper of development bank of Japan*, LA-51

Hashimoto H (2003): *Estimation of interregional Input-output table using cross entropy method*, Nagoya University

Hayase R (2006): Water quality management in closed water area, Japan society on water environment: *Handbook of water environment*, 21-4, 661-669

Hosoda E, Yokoyama A (2007) : *Environmental Economics*, Yuhikaku, Tokyo

Hosoe N, Gasawa K, Hashimoto H (2004) *Textbook of computable general equilibrium modeling*, University of Tokyo Press

Ishida S, Hanaki K, Aramaki T (2005) : Introduction of tradable permit system among sewage treatment plants in Tokyo bay watershed and its effect, *Journal of environmental systems and engineering*, 804: 73-81

Japan sewage works agency (2001): Sewage construction plan, *report of JSWA*

Kolstad C D (2000): *Environmental Economics*, Oxford University Press, 2000.

Ministry of Construction (1993) : *Handbook of metropolitan area in Japan*, Institute for area studies, Foundation

Ministry of Land, Infrastructure, Transport and Tourism in Japan (2003): On the possibility of introducing emission trading in installing sewer system, *research report of MLIT*.

Ministry of Land, Infrastructure, Transport and Tourism in Japan (2005): On the effects of introducing emission trading for reducing water pollution load from sewer system in Ise Bay Basin, *research report of Japan sewage works agency.*

Mitsubishi Research Institute (2006): *Business frontier regarding emission trading*, Kogyo chosakai publishing

Nishizawa E (2000) : Emission trading for water resource management in U.S.A. (1), Water science, 44-5:, 1-11

Nishizawa E (2001) : Emission trading for water resource management in U.S.A. (2), Water science, 44-6: 49-71

OECD (1999): *Implementing Domestic Tradable Permits for Environmental Protection*, OECD publications, Paris

Okuda T, Hashimoto H (2003): Estimation of interregional input-output table in urban level, *Proceedings of infrastructure planning*, 28, CD-ROM

Okuda T (2006): Estimation of interregional Input-output table employing entropy method, Okuda T : *CGE model for infrastructure planning in East Asia*, 2, 5-20

Shimada S, Watanabe H, Asami Y (2005) : Urban-rural water quality trading model to preserve sustainable water quality in Kasumigaura basin, *Journal of Japan society for impacts assessment*, 4-1: 65-76

Shoven, J. B. and Walley, J. : *Applying General Equilibrium*, University of Cambridge Press, 1992.

Optimal Regulations and Efficiency Losses in International Emissions Trading Under Different Market Structures

Tsung-Chen Lee, Hsiao-Chi Chen, and Shi-Miin Liu*

June 27, 2009

Abstract

This paper analyzes optimal regulations and efficiency losses in perfectly and imperfectly competitive international emissions trading (IET) systems. In perfect competition, it is optimal for countries to impose tax on their firms' permit trading. In imperfect competition, it is optimal for price-influencing countries to subsidize permit trading, but no regulation is optimal for price-taking countries. In the numerical analysis conducted for the Annex-1 emissions trading, we discover that total efficiency losses in perfect competition could be higher than those in imperfect competition. And some countries could be better-off under situations which are not globally cost-effective. The number as well as the composition of countries with market power would affect total efficiency losses under imperfect competition. However, governments' subsidies will promote permit trading and mitigate the losses caused by imperfectly competitive market structures.

Keywords: International emissions trading, market structures, optimal regulations, efficiency losses

JEL Classification: Q54, Q58

* Department of Economics at National Taipei University. The corresponding author is Tsung-Chen Lee with the e-mail address of tclee@mail.ntpu.edu.tw.

1. Introduction

International emissions trading (hereafter IET) is a flexible mechanism proposed in the Kyoto Protocol. Under this mechanism, the Annex-1 countries with different abatement costs could trade emission permits internationally. Many studies explore the global cost effectiveness of IET, i.e., a circumstance where a given global abatement goal is achieved in the cheapest way possible (e.g., Evans, 2003; Ciorba *et al*., 2001; Criqui *et al*., 1999; Kainuma *et al*., 1999; Weyant, 1999; Rose and Stevens, 1993). To reach the minimum of all trading countries' total compliance cost, each country's marginal abatement cost must equal the equilibrium price of emission permits, or these countries should have the same marginal abatement cost. This globally cost-effective trading rests on two important premises. One is a perfectly competitive IET market, in which all traders behave as price-takers. And the other is no government's regulation. Nevertheless, the two premises do not fit the real world well since imperfectly competitive market structures and governments' regulations are observed frequently.

In recent research on IET, a particular concern relating to the cost effectiveness of the Annex-1 emissions trading is Russian Federation's dominant role in supplying hot air. Therefore, lots of works focus on IET under imperfect competition (e.g., Böhringer *et al*., 2007; Klepper and Peterson, 2005; Böhringer and Löschel, 2003; Persson and Azar, 2003; Sager, 2003). This group of literature shows that Russian Federation's market power has caused both misallocations of the Annex-1 countries' abatement efforts and higher prices of emission permits. As a result, Russian Federation earns higher revenues and the price-taking importers of emission permits pay larger costs of compliance when compared to the trading under perfect competition. In contrast, little attention has been given to the issue of governments' regulations. Individual countries normally design their own climate policies from the perspective of self-interest, rather than from the viewpoint of global cost minimization. Despite that free trade is indispensable to achieve the global cost effectiveness, regulating IET might be attractive to individual countries because it is advantageous for a country to transfer part of its compliance cost to other countries. And regulating IET can be used to carry out such "cost-shifting" policies. Under the circumstances, one country's regulation could influence other participants in the permit-trading market, and the condition for the globally cost-effective IET system would be violated.

Accordingly, this study tries to investigate governments' optimal regulations under both perfectly and imperfectly competitive IET systems. In addition to deriving and characterizing the second best solutions for governments' and firms' behavior, we will examine efficiency losses caused by regulations as well as imperfect competition. To the authors' knowledge, this paper is the first to explore optimal regulations and efficiency losses of IET systems under different market structures. Relevant works include, among others, Rehdanz and Tol (2005), Ellerman *et al*. (1998) and Westskog (1996). Under perfect competition, Rehdanz and Tol (2005) analyze the impacts of allowance-importing regulations (e.g., tariff and quota) on equilibrium trading outcomes using a two-country model. By contrast, we allow both importing and exporting governments to endogenize their regulations in multi-country models. While Ellerman *et al*. (1998) focus on the impacts of governments' quantitative control on numerical equilibria, we assume that governments adopt price policy instruments of tariff and subsidy. And unlike us, Westskog (1996) investigates the relationship between market power and the size of efficiency loss in IET systems under imperfect competition and no regulation.

In this paper, two sequential games are constructed respectively for perfectly and imperfectly competitive IET systems. Players include trading countries' governments who serve as regulators and decide regulating degrees, and carbon-discharging firms who need to comply with the national emission caps and decide transaction amounts of the permits in the international market. Our setting differs from those modeling governments as permit traders (e.g., Westskog, 1996), but accords with some highlighting the impacts of regulations (e.g., Ellerman *et al*., 1998). We assume that there is only one representative firm as permit trader in each country. The same outcomes as Westskog's (1996) would result if governments' regulations are neglected.

We display that governments' optimal regulations would depend on market structures of IET and the number of countries with market power. If the market is competitive, governments will impose tax on firms' permit trading. On the other hand, if the imperfectly competitive market has only one price-influencing country, no regulation is optimal for all countries. However, if the imperfectly competitive market has at least two price-influencing countries, it is optimal for governments in these countries to subsidize their firms' purchases or sales of emission permits, but price-taking countries' governments should not intervene in the trading. These intuitions are given below. In the perfectly competitive IET system considering no regulation, firms' marginal abatement costs always equal permit price at equilibrium. Thus, the best "cost-shifting" policies are to change permit price in a desired direction. And taxing permit trading will induce the change. In the imperfectly competitive IET system considering no regulation, price-influencing permit buyers (sellers) have a marginal abatement cost greater (smaller) than permit price at equilibrium. Thus, the best “cost-shifting” policies are to expand the permit trading volume. Subsidies will induce the desired effect of expanding trading volume although they will also lead to an undesired minor change of permit price. This result is parallel to Brander and Spencer’s (1985), which states that subsidizing is exporting country’s best policy due to the distortion of imperfect competition. However, unlike Brander and Spencer (1985), in our model firms’ importing or exporting permits are endogenously determined, hence optimal subsidy polices apply to both price-influencing exporters and importers. Moreover, we explain the roles of price-taking countries and explicitly explore their optimal policies under both perfect and imperfect competition.

To further understand efficiency losses caused by exercises of market power and governments’ regulations, we develop a numerical analysis of the Annex-1 emissions trading. The results not only support our theoretical outcomes, but provide us with new insights. We demonstrate that relative magnitudes of social costs in the globally cost-effective case and in IET systems considering governments’ regulations are uncertain. Therefore, some countries could become better-off under scenarios that are not globally cost-effective. In addition, the total efficiency loss in the imperfectly competitive IET system is affected by both the number and composition of price-influencing players. This supplements Westskog’s (1996) finding, which indicates that the total efficiency loss would increase with the number of price-influencing players. Finally, although exercises of market power cause efficiency losses, subsidy policies employed by price-influencing governments facilitate permit trading and mitigate the losses caused by imperfect competition. In contrast, tax policies in a competitive IET system would impede permit trading, and might result in higher efficiency losses, as compared with the imperfect competition case.

The remainder of this paper is organized as follows. Section 2 describes basic settings of our models. Section 3 presents the globally cost-effective equilibrium. Perfectly and imperfectly competitive IET systems considering governments’ regulations are explored in Sections 4 and 5, respectively. The numerical results of the Annex-1 emissions trading are reported in Section 6, and the associated equilibria are contrasted with those in the globally cost-effective case. Finally, conclusions are drawn in Section 7.

2. Basic Settings

Consider a partial equilibrium model of emissions trading among N countries with $N \geq 2$.

Assume that each country has a representative firm. Let us focus on an IET system already having an international agreement on the allocation of emission caps (or emission permits). Thus, the maximum emission amounts for all participating countries are limited. Denote $\overline{w}_i$ the exogenous emission cap assigned to country i. The emissions caps can be achieved by self-abatement. Let $C_i(e_i)$ be firm i's abatement cost function associated with emitting e_i, $e_i \geq 0$. Assume that marginal abatement costs, $-C_i'(e_i)$, are positive and increasing, i.e., $C_i'(e_i) < 0$ and $C_i''(e_i) > 0$ for $i = 1,...,N$ and $\forall e_i \geq 0$.

With an IET system, firms could also meet their emission caps by trading emission permits under price p in the international market. Firm i's transaction amount is the difference between its actual emission level e_i and emission cap $\overline{w}_i$. If $e_i > (<)\, \overline{w}_i$, firm i purchases (sells) emission permits. Accordingly, $(e_i - \overline{w}_i)$ represents firm i's excess demand for permits, $i = 1,...,N$. A firm having positive excess demand is a permit buyer, while a firm having negative excess demand (i.e., excess supply) is a permit seller.

When firms trade, their governments could choose to regulate. Here we will focus on price regulating instruments. Denote t_i government i's regulation condition. If firm i purchases emission permits, $t_i > (<)\, 0$ means that a tax (subsidy) is levied on (distributed to) the purchases. If firm i sells emission permits, $t_i > (<)\, 0$ implies that a subsidy (tax) is distributed to (levied on) the sales. And $t_i = 0$ signifies no government's regulation. Using regulating policies with positive t_i means that firms will pay higher costs to buy or receive more revenues to sell permits in the IET system, hence encouraging domestic abatement and being called a "green" policy. Oppositely, negative t_i discourages domestic abatement and is called a "brown" policy.

Next, we introduce the objective functions for firms and governments. Firm i's compliance cost consists of self-abatement cost and permit trading expenditure (or revenue). That is,

$$FC_i(e_i) \equiv C_i(e_i) + (p + t_i)(e_i - \overline{w}_i), \quad i = 1,...,N, \tag{1}$$

where positive $(p + t_i)(e_i - \overline{w}_i)$ represents firm i's permit trading expenditure while negative $(p + t_i)(e_i - \overline{w}_i)$ is the permit trading revenue. On the other hand, country i's social cost equals firm i's compliance cost subtracting the imposed tax (or distributed subsidy). Since the tax (or subsidy) is transfer payment between governments and their own firms, country i's social cost can be rewritten as

$$SC_i\,(t_i) \equiv C_i(e_i) + p(e_i - \overline{w}_i)\,,\;\; i = 1,...,N\,. \tag{2}$$

Based on the settings, various results are derived and compared in the following sections.

3. Globally Cost-Effective IET

This section presents our benchmark case of competitive IET considering no government's regulation, which is called the globally cost-effective IET system. Precisely, N firms choose their optimal emissions, $\{e_i^g\}_{i=1}^N$, to minimize the global compliance cost. Then, firms trade their emission permits in the competitive market, and equilibrium permit price p^g is determined through the market-clearing condition. That is, $\{e_1^g,...,e_N^g, p^g\}$ solves the problem of

$$\min_{\{e_i\}_{i=1}^N,\,p} \sum_{i=1}^{N} [C_i(e_i) + p(e_i - \overline{w}_i)]\,, \tag{3}$$

$$\text{s.t.}\;\; \sum_{i=1}^{N} e_i = \sum_{i=1}^{N} \overline{w}_i\,. \tag{4}$$

The associated first-order conditions for an interior solution are

$$-C_i'(e_i^g) = p\,,\;\; i = 1,...,N\,. \tag{5}$$

Equation (5) means that price-taking firm i will adjust its emissions until the marginal cost of abatement ($-C_i'(e_i^g)$) equals the marginal saving of abatement (p). This globally cost-effective condition implies the equality of marginal abatement costs across countries at equilibrium. Equation (5) implicitly defines the demand function for permits, $e_i^g = e_i^g(p)$, which is downward sloping, i.e., $\dfrac{\partial e_i^g}{\partial p} = \dfrac{-1}{C_i''(e_i^g)} < 0$, $i = 1,...,N$. In other words, the higher is the permit price, the lower are firms' optimal emissions.

Equilibrium permit price can be solved by substituting $e_i^g = e_i^g(p)$ into market-clearing condition (4). That is,

$$\sum_{i=1}^{N} e_i^g(p^g) = \sum_{i=1}^{N} \overline{w}_i\,. \tag{6}$$

Substituting $\{e_1^g,...,e_N^g, p^g\}$ into (2) yields country i's social cost at equilibrium of the system,

$$SC_i^g \equiv C_i(e_i^g) + p^g(e_i^g - \overline{w}_i) \quad \text{for} \quad i = 1, ..., N. \tag{7}$$

The IET system operates in the most efficient way such that the total cost of complying with the global abatement target is minimized. This is our benchmark when evaluating efficiency losses of other systems due to governments' regulations and imperfect competition.

4. Competitive IET Considering Governments' Regulations

In this section, we add governments' regulations into the competitive IET system to explore optimal regulating policies. This sequential game proceeds as follows. In the first stage, government i chooses t_i^*, $i = 1, ..., N$, to minimize the social cost of country i. Then, given t_i^*, firm i selects optimal emission level e_i^* to minimize its cost of complying with emission cap $\overline{w}_i$. Next, all firms trade emission permits in the competitive market, and equilibrium permit price p^* is determined. Therefore, $\{\{t_i^*\}_{i=1}^N, \{e_i^*\}_{i=1}^N, p^*\}$ constitutes a subgame perfect equilibrium (hereafter SPE) of this game.

The SPE of the game is derived by the backward induction method as follows. We assume the associated second-order conditions in each stage hold and omit their derivation. First, given tax or subsidy t_i and permit price p, firm i chooses e_i^* to solve the problem of

$$\min_{e_i \geq 0} FC_i(e_i) = C_i(e_i) + (p + t_i)(e_i - \overline{w}_i), \quad i = 1, ..., N. \tag{8}$$

The corresponding first-order conditions for an interior solution are

$$-C_i'(e_i^*) = p + t_i \quad \text{for} \quad i = 1, ..., N. \tag{9}$$

Equation (9) implies that firm i will adjust its emissions until the marginal cost of abatement ($-C_i'(e_i^*)$) equals the marginal saving of abatement, and the latter is composed of permit price (p) and the tax imposed or subsidy distributed (t_i). Therefore, e_i^* can be expressed as a function of (p, t_i), i.e., $e_i^* = e_i^*(p, t_i)$, with $\dfrac{\partial e_i^*}{\partial p} = \dfrac{\partial e_i^*}{\partial t_i} = \dfrac{-1}{C_i''(e_i^*)} < 0$.

Substituting $e_i^* = e_i^*(p, t_i)$ into market-clearing condition (4), we can obtain equilibrium permit price $p^* = p^*(\{t_i\}_{i=1}^N)$, with

$$\frac{\partial p^*}{\partial t_i} = \frac{-(\partial e_i^* / \partial t_i)}{\sum_{k=1}^{N} (\partial e_k^* / \partial p)}, \quad i = 1, ..., N, \tag{10}$$

where $-1 < \frac{\partial p^*}{\partial t_i} < 0$ given $\frac{\partial e_i^*}{\partial p} = \frac{\partial e_i^*}{\partial t_i} < 0$ by (9). Derivative $\frac{\partial p^*}{\partial t_i}$ can be interpreted as a "pass-through" effect, which measures the amount of tax (or subsidy) passed through to equilibrium permit price. Based on equation (10), the "pass-through" effect is negative. An increase in t_i represents a greener policy that encourages domestic abatement. Then both excess demand for emission permits and equilibrium permit price decline. Moreover, the absolute value of the derivative is less than one, implying that the degree of equilibrium permit price decrease is smaller than that of t_i's increase.

Now turn to the first stage of the game. Given $\{e_i^*\}_{i=1}^N$ and p^*, government i chooses t_i^* to solve the problem of

$$\min_{t_i \in R} SC_i(t_i) = C_i(e_i^*) + p^*(e_i^* - \overline{w}_i), \quad i = 1, ..., N. \tag{11}$$

The corresponding first-order conditions for an interior solution are

$$\left(C_i'(e_i^*) + p^*\right)\left(\frac{\partial e_i^*}{\partial t_i}\right) + \left(\frac{\partial p^*}{\partial t_i}\right)(e_i^* - \overline{w}_i) = 0 \quad \text{for} \quad i = 1, ..., N. \tag{12}$$

Substituting (9) into (12) and rearranging yield

$$t_i^* = \Omega_i (e_i^* - \overline{w}_i) \quad \text{for} \quad i = 1, ..., N, \tag{13}$$

where $\Omega_i = \frac{(\partial p^* / \partial t_i)}{(\partial e_i^* / \partial t_i)} > 0$ by (9) and (10).

Equation (13) implies that it is optimal for all countries to regulate IET under perfect competition unless firms' optimal emissions equal their required emission caps, i.e., $e_i^* = \overline{w}_i$ for all is. Moreover, by $\Omega_i > 0$ for all is, equation (13) suggests that

$$t_i^* \begin{matrix} > \\ = \\ < \end{matrix} 0 \quad \text{iff} \quad e_i^* \begin{matrix} > \\ = \\ < \end{matrix} \overline{w}_i, \quad i = 1, ..., N. \tag{14}$$

Equation (14) states that all governments will impose tax on permit trading no matter their firms buy or sell. The intuition is as follows. In a competitive IET system considering no regulation, firms have no benefit by trading more permits since marginal abatement cost always equals permit price at equilibrium. Thus, government's optimal policy should be able to change permit price in its firm's desired direction. To have a lower price, permit-buying countries should tax permit trading to reduce firms' excess demand. In contrast, to have a higher price, permit-selling countries ought to tax permit trading to decrease firms' excess supply. These outcomes are summarized below.

Theorem 1. *In a perfectly competitive IET system, it is optimal for countries to tax their firms' trading of emission permits*.

Proof. See the Appendix.

5. Imperfectly Competitive IET Considering Governments' Regulations

This section explores governments' optimal regulations in IET under imperfect competition. As in Westskog (1996), we model the imperfect competition as a leader-follower game, in which price-influencing countries are leaders, and the rest are price-taking followers.

In an IET system with N players, let the first L ($1 \le L < N$) players, indexed by $m = 1,...,L$, have market power; and the rest $(N-L)$ players, indexed by $n = (L+1),..,N$, be price-takers. Our game structure is parallel to Westskog's (1996), characterizing the circumstance where equilibrium permit price is exclusively determined by the price-influencing countries. Hence governments and firms with market power move first. Precisely, our sequential game proceeds as follows. First, government m with market power, $m = 1,...,L$, chooses $\hat{t}_m$ to minimize its social cost. Second, given $\hat{t}_m$, firm m with market power selects optimal emission level $\hat{e}_m$ to minimize its compliance cost. And equilibrium permit price $\hat{p}$ is determined based on the market-clearing condition. Third, given $\hat{p}$, price-taking government n, $n = (L+1),..,N$, chooses $\hat{t}_n$ to minimize its social cost. Finally, given $\hat{p}$ and $\hat{t}_n$, price-taking firm n selects optimal emission level $\hat{e}_n$ to minimize its compliance cost. Thus, $\{\{\hat{t}_i\}_{i=1}^{N}, \{\hat{e}_i\}_{i=1}^{N}, \hat{p}\}$ constitutes a SPE of this game.

The SPE is derived by the backward induction method below. Again, we assume the associated second-order conditions in each stage hold and omit their derivation. First, given tax or subsidy t_n and permit price p, price-taking firm n chooses $\hat{e}_n$ to solve a problem similar to (8). Accordingly, we derive the associated first-order conditions similar to (9). That is,

$$-C_n'(\hat{e}_n) = p + t_n, \quad n = (L+1),.., N . \tag{15}$$

Based on (15), $\hat{e}_n$ can be expressed as a function of (p, t_n), i.e., $\hat{e}_n = \hat{e}_n(p, t_n)$ with

$$\frac{\partial \hat{e}_n}{\partial p} = \frac{\partial \hat{e}_n}{\partial t_n} = \frac{-1}{C_n''(\hat{e}_n)} < 0, \quad n = (L+1),.., N .$$

Second, given firm n's optimal emissions $\hat{e}_n$ and permit price p, price-taking government n, $n = (L+1),.., N$, chooses $\hat{t}_n$ to solve the problem of

$$\min_{t_n \in R} SC_n(t_n) = C_n(\hat{e}_n) + p\,(\hat{e}_n - \overline{w}_n). \tag{16}$$

The associated first-order conditions for an interior solution are

$$\left(C_i'(\hat{e}_n) + p\right)\left(\frac{\partial \hat{e}_n}{\partial t_n}\right) = 0, \quad n = (L+1),.., N . \tag{17}$$

Since $\frac{\partial \hat{e}_n}{\partial t_n} < 0$ by (15), equation (17) implies that $C_i'(\hat{e}_n) + p = 0$. Combining this with (15), we have

$$\hat{t}_n = 0, \quad n = (L+1),.., N . \tag{18}$$

Equation (18) means that it is optimal for price-taking governments not to intervene in IET under imperfect competition. In the competitive IET system, price-taking countries could benefit from taxing permit trading because their aggregate behavior would alter equilibrium permit price. However, the price-taking countries in the imperfectly competitive IET system have no benefit by taxing or subsidizing permit trading since equilibrium permit price is determined before the countries' regulation decisions. Thus, no regulation is optimal for the price-taking countries.

Third, given $\{\hat{e}_n, \hat{t}_n\}_{n=L+1}^{L}$ and government m's tax or subsidy t_m, firm m with market power will choose emission level $\hat{e}_m$ to minimize its compliance cost subject to the market-clearing condition. That is, $\hat{e}_m$ is the solution of the following problem.

$$\min_{e_m \geq 0} FC_m(e_m) = C_m(e_m) + (p + t_m)\,(e_m - \overline{w}_m), \quad m = 1,..., L, \tag{19}$$

$$\text{s.t.} \quad \sum_{m=1}^{L} e_m + \sum_{n=L+1}^{N} \hat{e}_n = \sum_{i=1}^{N} \overline{w}_i \ . \tag{20}$$

Based on (15) and (18), we have $\hat{e}_n = \hat{e}_n(p)$, $n = (L+1),..,N$. Substituting this into market-clearing condition (20) and rearranging it give

$$\sum_{n=L+1}^{N} \hat{e}_n(p) = \sum_{i=1}^{N} \overline{w}_i - \sum_{m=1}^{L} e_m \ . \tag{21}$$

According to (21), p can be expressed as a function of $\{e_m\}_{m=1}^{L}$ with

$$\frac{\partial p}{\partial e_m} = \frac{-1}{\sum_{n=L+1}^{N} (\partial \hat{e}_n / \partial p)} > 0 \ , \quad m = 1,...,L \ . \tag{22}$$

Equation (22) indicates that a positive relationship exists between permit price and price-influencing firm m 's emissions. If firm m emits more, then permits available to the price-taking firms reduce. This will lead to an increase in permit price.

Substituting $p = p(\{e_m\}_{m=1}^{L})$ from (22) into objective function (19) and deriving the first-order conditions for an interior solution $\hat{e}_m$ yield

$$-C_m'(\hat{e}_m) = p + t_m + \left(\frac{\partial p}{\partial e_m}\right)(\hat{e}_m - \overline{w}_m), \quad m = 1,...,L \ . \tag{23}$$

Equation (23) implies that firm m will adjust its emissions until the marginal cost of abatement ($-C_m'(\hat{e}_m)$) equals the marginal saving of abatement, and the latter is composed of three parts: permit price (p), tax or subsidy of permit trading (t_m), and marginal price effect from market power ($\left(\frac{\partial p}{\partial e_m}\right)(\hat{e}_m - \overline{w}_m)$). The marginal price effect is positive for permit buyers, meaning that one more unit of abatement (or decrease in emission) leads to a saving of trading expenditure by $\left(\frac{\partial p}{\partial e_m}\right)(\hat{e}_m - \overline{w}_m)$. Oppositely, the marginal price effect is negative for permit sellers, implying that an additional unit of abatement would reduce trading revenue by $\left(\frac{\partial p}{\partial e_m}\right)(\hat{e}_m - \overline{w}_m)$.

According to (23) and the implicit function theorem, $\hat{e}_m$ can be expressed as a function of

$(t_1,...,t_L)$. That is, $\hat{e}_m = \hat{e}_m(\{t_r\}_{r=1}^{L})$ for $m = 1,...,L$ with

$$\frac{\partial \hat{e}_m}{\partial t_m} < 0 \text{, and} \quad (24)$$

$$\frac{\partial \hat{e}_m}{\partial t_r} > 0 \quad \text{for} \quad m, r = 1,...,L \quad \text{and} \quad m \neq r. \quad (25)$$

Proofs of (24) and (25) are in the Appendix. An increase in t_m will enhance the marginal saving of abatement. Therefore, firm m will abate more and discharge fewer emissions. On the other hand, if government r adopts a greener policy (higher t_r), then firm r's emissions would be lower. It will lead to a decrease in both excess demand and permit price. For firm m, a lower permit price results in a smaller marginal saving of abatement. Thus, it will emit more. Since $\hat{e}_m = \hat{e}_m(\{t_r\}_{r=1}^{L})$, equation (21) implies that equilibrium permit price is also affected by $\{t_r\}_{r=1}^{L}$, i.e., $\hat{p} = \hat{p}(\{t_r\}_{r=1}^{L})$.

Finally, given all firms' optimal emissions $\{\hat{e}_i\}_{i=1}^{N}$, price-taking countries' optimal taxes or subsidies $\{\hat{t}_n\}_{n=L+1}^{N}$, and equilibrium permit price $\hat{p}$, government m would choose $\hat{t}_m$ to solve the problem of

$$\min_{t_m \in R} SC_m(t_m) = C_m(\hat{e}_m) + \hat{p}(\hat{e}_m - \overline{w}_m), \quad m = 1,...,L. \quad (26)$$

The associated first-order conditions for an interior solution are

$$\left(C'_m(\hat{e}_m) + \hat{p}\right)\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) + \left(\frac{\partial \hat{p}}{\partial t_m}\right)\left(\hat{e}_m - \overline{w}_m\right) = 0, \quad m = 1,...,L. \quad (27)$$

Substituting (23) into (27) and rearranging it yield

$$\hat{t}_m = \Pi_m(\hat{e}_m - \overline{w}_m), \quad m = 1,...,L, \quad (28)$$

where

$$\Pi_m = \left[\left(\frac{\partial \hat{p}}{\partial t_m}\right) - \left(\frac{\partial p}{\partial e_m}\right)\left(\frac{\partial \hat{e}_m}{\partial t_m}\right)\right]\left(\frac{\partial \hat{e}_m}{\partial t_m}\right)^{-1} \begin{cases} = 0 & \text{if} \quad L = 1, \\ < 0 & \text{if} \quad L \geq 2. \end{cases} \quad (29)$$

Proof for (29) is in the Appendix. Unlike price-taking countries, price-influencing governments will regulate the international permit trading unless their firms' emissions equal corresponding required caps (i.e., $\hat{e}_m = \overline{w}_m$) or there is only one price-influencing country (i.e., $L = 1$). If only one price-influencing country exists, this country has unique power to influence equilibrium permit price, and has no need to regulate. In contrast, if there are two or more price-influencing players, then equations (28) and (29) suggest that

$$\hat{t}_m \begin{matrix} > \\ = \\ < \end{matrix} 0 \quad \text{iff} \quad \hat{e}_m \begin{matrix} < \\ = \\ > \end{matrix} \overline{w}_m , \quad m = 1,...,L . \tag{30}$$

Equation (30) says that government m will subsidize firm m's permit trading unless its optimal emission equals the required cap. The policy intuition is as follows. In an imperfectly competitive IET system considering no regulation, price-influencing permit buyers have a marginal abatement cost greater than equilibrium permit price due to $\left(\frac{\partial p}{\partial e_m}\right)(\hat{e}_m - \overline{w}_m) > 0$ from (23). It means that buyer's marginal cost of abatement exceeds its marginal cost of permit purchase, that is, increasing the purchase is beneficial. Therefore, price-influencing governments will encourage their firms' participation in IET. And subsidy, instead of tax, policy could help achieve this goal. Subsidizing firms' permit purchases would raise permit-purchasing costs, i.e., $\frac{\partial \hat{p}}{\partial t_m} < 0$, because more excess demand will increase equilibrium permit price. However, the subsidy policy also induces a quantity effect of permit purchasing, i.e., $-\left(\frac{\partial p}{\partial e_m}\right)\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) > 0$, which would lower firms' abatement costs. Since $\Pi_m < 0$ by (29) and $\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) < 0$ by (24), we have $\left(\frac{\partial \hat{p}}{\partial t_m}\right) - \left(\frac{\partial p}{\partial e_m}\right)\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) > 0$. That is, the desired quantity effect dominates the undesired price effect. Thus, it is optimal for permit-buying countries to employ a subsidy policy.

By similar arguments, subsidy is also the best choice for permit-selling countries. Equation (23) implies that price-influencing permit sellers have a marginal abatement cost smaller than equilibrium permit price when no regulation is considered. In other words, seller's marginal cost is lower than its marginal revenue of permit sale. Enlarging permit sale is therefore beneficial. Subsidizing price-influencing permit sellers will decrease their revenues due to lower price, but increase the revenues due to higher trading amount. Since the desired quantity effect will dominate the undesired price effect, it is optimal for permit-selling countries to adopt this policy. Optimal regulating policies in an imperfectly competitive IET system are summarized as follows.

Theorem 2. *In an imperfectly competitive IET system, no regulation is optimal for the price-taking countries. For countries with market power, their optimal policies will depend on the size of their group. When only one price-influencing country exists, no regulation is optimal. However, if price-influencing countries are more than one, it is optimal for these countries to subsidize their firms' permit trading.*

Proof. See the Appendix.

6. A Numerical Analysis of the Annex-1 Emissions Trading

In this section we conduct a numerical analysis of the Annex-1 emissions trading using models developed in Sections 3-5 and data of the Annex-1 countries. The results will help verify our theoretical outcomes and demonstrate efficiency losses of the IET systems with different market structures.

Suppose we have a quadratic abatement cost function

$$C_i(e_i) = (1/2)\,\alpha_i\,(\overline{b}_i - e_i)^2,\quad i = 1, 2, ..., N, \tag{31}$$

where $\overline{b}_i$ is the unconstrained baseline emission level for the representative firm in country i, i.e., the emission amount under no abatement; representative firm i's abatement level thus equals $(\overline{b}_i - e_i)$; $\alpha_i > 0$ is a technological parameter and increasing with falling abatement efficiency.

For simplicity and significant status of large per-capita carbon-emission countries, the Annex-1 group considered here includes Russia (country 1), the European Union (country 2), the US (country 3), and Japan (country 4). Table 1 summarizes the data used. Emissions $\overline{b}_i$ and emission caps $\overline{w}_i$ for $i = 1, 2, 3, 4$, originating from the OECD GREEN model (OECD, 1999), are taken from the GTAP-E model (Burniaux and Truong, 2002). The emission caps ($\overline{w}_i$) for the Annex-1 countries are those required relative to their associated emission levels in an unconstrained baseline scenario ($\overline{b}_i$). Except Russia, we have $\overline{b}_i > \overline{w}_i$, $i = 2, 3, 4$. Thus, $(\overline{b}_i - \overline{w}_i)$, $i = 2, 3, 4$, represent corresponding abatement levels required by the Kyoto Protocol. For Russia, we have $\overline{b}_1 < \overline{w}_1$. Therefore, $(\overline{w}_1 - \overline{b}_1)$ is the amount of hot air that could be sold in the international emissions trading market. The hot air is mainly caused by the economic disarray following the collapse of

Soviet Union. Values of parameter α_i are estimated based on the GTAP-E model for $i = 1, 2, 3, 4$.

[Table 1 around here]

Paralleling our theoretical models, three types of simulation scenarios would be illustrated. The first and second types correspond to the globally cost-effective IET and the competitive IET considering governments' regulations displayed in Sections 3 and 4, respectively. Each of the two types contains only one scenario, i.e., all countries act as price-takers. The third type corresponds to imperfectly competitive IET systems shown in Section 5. Fourteen simulation scenarios are included in this type. Among them, four have one country with market power, six have two countries with market power, and the rest four have three countries with market power. All simulation scenarios are summarized in Table 2.

[Table 2 around here]

Table 3 reports equilibrium permit prices obtained in all simulation scenarios. The four Annex-1 countries' optimal emissions, permit-purchasing amounts and social costs in the globally cost-effective IET scenario are displayed in Table 4, so are simulation results for the scenario of competitive IET considering governments' regulations. The numerical outcomes for imperfectly competitive IET systems with one, two, and three price-influencing countries are presented in Tables 5, 6, and 7, respectively.

Units and signs for numerical results in Tables 4-7 are explained below. Optimal emissions and permit trading amounts are measured by million tons of carbon (MtC). Countries with positive (negative) values in rows of "permit purchases" are permit buyers (sellers). Optimal regulations t_i are measured by US dollars per ton of carbon (US$/tC). As in Section 2, if firm i purchases emission permits, $t_i > (<) 0$ means that its government taxes (subsidizes) the purchases. In contrast, if firm i sells permits, $t_i > (<) 0$ suggests that its government subsidizes (taxes) the sales. Countries' social costs are appraised by millions of US dollars. And their efficiency losses under various scenarios are reckoned by subtracting their social costs in the globally cost-effective IET scenario from those in the corresponding scenarios, and are measured by millions of US dollars. Countries with positive (negative) efficiency losses have efficiency losses (gains).

[Tables 3-7 around here]

Optimal regulations of the four countries in Scenarios 2-16 are consistent with our Theorems 1 and 2, as manifested in Tables 4-7. In the competitive IET system (Scenario 2 in Table 4), it is optimal for the exporting country (Russia) to tax permit sales, and for importing countries (the EU, the US, and Japan) to tax permit purchases. In the imperfectly competitive IET system with one price-influencing country (Scenarios 3-6 in Table 5), no regulation is optimal. For cases with more than one price-influencing countries (Scenarios 7-16 in Tables 6-7), it is optimal for price-influencing countries to subsidize permit trading and for price-taking countries not to intervene.

Individual countries' social costs and trading efficiency are determined by, in addition to regulating degree, equilibrium permit price and firms' optimal emission levels. Therefore, in the following, we will first compare the numerical results of these two variables between Scenario 1 and Scenarios 2-16 in pairs. Then an overall comparison among all scenarios is conducted to illustrate individual countries' efficiency losses as well as total efficiency losses under various market structures.

Based on Table 3, the relative magnitudes of equilibrium permit price in Scenario 1 (the globally cost-effective case) to those in Scenarios 2-16 are uncertain. The equilibrium permit price in Scenario 2 (p^* = \$87.32/tC) is lower than that in Scenario 1 (p^g =\$90.79/tC), since tax regulations reduce the excess demand for permits. For the imperfectly competitive IET systems with one price-influencing country, we have $\hat{p} > p^g$ if and only if the country with market power is a seller. Therefore, $\hat{p} > p^g$ in Scenario 3 (Russia having market power) while $\hat{p} < p^g$ in Scenarios 4-6 (the EU, the US or Japan having market power). For scenarios with more than one price-influencing countries and they are all buyers (Scenarios 10, 11, 12 and 16), we have $\hat{p} < p^g$. For scenarios where countries with market power include permit buyers and sellers, relative magnitudes of p^g and $\hat{p}$ are uncertain.

The relative magnitudes of firm i's optimal emissions in Scenario 1 to those in Scenarios 2-16 depend on relative marginal savings of abatement in the corresponding pair-wise scenarios, as suggested by equations (5), (9), (15) and (23). Take Scenario 7, where Russia and the EU have market power, as an example. Tables 4 and 6 disclose that optimal emissions of the EU, the US and Japan in Scenario 1 are all higher than their emissions in Scenario 7. And Russia has the opposite result. The reasons are as follows. The marginal saving of abatement in the global cost-effective case is $p^g = \$90.79/\text{tC}$ for all countries. In Scenario 7, the marginal saving for price-taking US and Japan equals $\hat{p} = \$91.50/\text{tC}$, which is higher than p^g. Thus, we have $\hat{e}_i < e_i^g$, $i = 3, 4$. For price-influencing Russia, we have $\hat{e}_1 > e_1^g$ because its marginal saving of abatement ($\$74.70/\text{tC}$, calculated based on (23)) is smaller than $p^g = \$90.79/\text{tC}$. In contrast, for price-influencing EU, we have $\hat{e}_2 < e_2^g$ because its marginal saving of abatement ($\$98.58/\text{tC}$, calculated based on (23)) is higher than $p^g = \$90.79/\text{tC}$. Similar arguments can be applied to other scenarios.

The relative magnitudes of country i's social costs in Scenario 1 to those in Scenarios 2-16 are uncertain, and they are summarized as follows. First, for scenarios with only one price-influencing country (Scenarios 3-6), social costs of the price-influencing countries will always be lower than their counterparts in Scenario 1 (the globally cost- effective case), because they have the first-mover advantage in determining permit price. Second, for scenarios with more than one price-influencing country, social costs of the price-influencing countries may be higher or lower than their counterparts in Scenario 1. For example, Russia and the EU in Scenario 7 have higher social costs relative to Scenario 1. Finally, price-taking countries' social costs may be higher or lower than their counterparts in Scenario 1. For instance, Japan's social cost in Scenario 10 is lower than its cost in Scenario 1. These results imply that some countries could be better-off under situations which are not globally cost-effective.

In the following, we illustrate efficiency losses under different IET market structures by comparing countries' total social costs in various scenarios. As indicated in Section 3, the countries' total social cost is the lowest in the globally cost-effective case. Thus, scenarios 2-16 all have higher total social costs and efficiency losses, as compared with Scenario 1. Among these scenarios, the highest efficiency loss occurs in Scenario 13 (Russia, the EU and the US having market power) and the lowest happens in Scenario 6 (Japan having market power).

Moreover, two important outcomes are observed. First, the total efficiency loss in the competitive IET system (Scenario 2) could be higher than those in imperfectly competitive IET systems (Scenarios 3, 4, 5, 6, 7, 9, 10, 11, 12, 14 and 16). That is because subsidy policies employed by the price-influencing countries could facilitate permit trading and mitigate the distortion caused by imperfectly competitive market structures. In Tables 6-7, we decompose the sources of total efficiency losses in the imperfectly competitive IET systems into exercises of market power and governments' regulations. The total efficiency losses due to regulations are all negative in Scenarios 7-16, meaning that regulations actually bring efficiency gains. In contrast, taxing permit trading in a competitive IET system might result in higher efficiency losses.

Second, in addition to the number of countries with market power, as noted in Westskog (1996), our numerical results show that the composition of these countries will also influence the sizes of total efficiency losses. Basically, adding countries with market power will lead to higher total efficiency losses. For example, Russia is the price-influencing country in Scenario 3, and the total efficiency loss equals US$121.51 millions. In addition to Russia, Scenarios 7, 8, 9, 13, 14 and 15 assume that other countries have market power and all of these scenarios have higher total efficiency losses. However, if the price-influencing countries are not exactly the same, more countries with market power may decrease the total efficiency loss. For instance, Scenario 8 assumes that Russia and the US have market power, and the total efficiency loss is US$452.25 millions. In contrast, Scenario 16 presumes that the EU, the US and Japan have market power, and the total efficiency loss is merely US$157.27 millions. Consequently, both the number and composition of countries with market power affect the total efficiency loss.

7. Conclusions

This paper analyzes optimal regulations and efficiency losses in international emissions trading under different market structures. In perfect competition, it is optimal for all countries to impose tax on their firms' permit trading. In imperfect competition, no regulation is optimal for price-taking countries. For countries with market power, however, optimal regulations will depend on the number of the price-influencing countries. When there exists only one price-influencing country, no regulation is optimal. In contrast, if price-influencing countries are more than one, then it is optimal for these countries to subsidize their firms' permit trading.

To support our theoretical outcomes and to measure total efficiency losses under different market structures, a numerical analysis of the Annex-1 emissions trading is conducted. By comparing equilibria of various IET systems considering governments' regulations with those of the globally cost-effective system, we discover that equilibrium permit prices, firms' optimal emissions, as well as countries' social costs under different market structures may be higher or lower than their counterparts in the globally cost-effective system. In other words, countries could have lower social costs in scenarios which are not globally cost-effective. The total efficiency losses due to governments' regulations in the perfectly competitive IET system could be higher than those in the imperfectly competitive IET systems. The efficiency losses in the latter are affected by both the number and composition of countries with market power. And subsidy policies adopted by the price-influencing governments will promote permit trading and mitigate efficiency losses caused by imperfectly competitive market structures.

This paper presumes an international agreement on initial permit allocations. This assumption can be relaxed in the future. Then, optimal allocations of emission permits and the conditions under which countries are willing to participate in international emissions trading can be explored. On the other hand, investigating the impacts of sequential games' settings on equilibrium results can be a worthy research topic. For instance, we can first let all countries select their optimal regulations simultaneously, then allow the price-influencing firms to move, next admit the rest price-taking firms to act. Since the first-mover advantage may not exist, some of our outcomes, such as optimal regulations, may change accordingly.

Appendix

***Proof of Theorem 1*:**

From (9) and (12), the impacts of t_i on the country's social cost could be decomposed into a quantity and a price effects. That is,

$$\frac{dSC_i}{d\,t_i} = -t_i\left(\frac{\partial\, e_i^*}{\partial\, t_i}\right) + \left(\frac{\partial\, p^*}{\partial\, t_i}\right)(e_i^* - \overline{w}_i) \quad \text{for} \quad i = 1,\ldots,N\,.$$

Permit-buying country i $(e_i^* > \overline{w}_i)$ will always have a negative price effect, i.e., $\left(\frac{\partial\, p^*}{\partial\, t_i}\right)(e_i^* - \overline{w}_i) < 0$ since $\frac{\partial\, p^*}{\partial\, t_i} < 0$ by (10). If policy $t_i \le 0$ is adopted, a negative or zero quantity effect arises, i.e., $-t_i\left(\frac{\partial\, e_i^*}{\partial\, t_i}\right) \le 0$ due to $\frac{\partial\, e_i^*}{\partial\, t_i} < 0$ by (9). Combining the two effects, we have $\frac{dSC_i}{d\,t_i} < 0$. It means that the optimal regulation should be $t_i^* = \infty$, which contradicts with $t_i \le 0$. Thus, policy $t_i \le 0$ will never be optimal for a permit-buying country.

In contrast, permit-selling country i has $e_i^* < \overline{w}_i$, thus has a positive price effect. Adopting policy $t_i \ge 0$ will lead to a positive or zero quantity effect. Therefore, we have $\frac{dSC_i}{d\,t_i} > 0$. It means that the optimal regulation should be $t_i^* = -\infty$, which contradicts with $t_i \ge 0$. Thus, policy $t_i \ge 0$ will never be optimal for a permit-selling country.

***Proof of Equation (24)*:**

Let matrix H be the Hessian matrix of L equations in (23) with

$$H = \begin{bmatrix} C_1''(\hat{e}_1) + 2A & A & \cdots & A \\ A & C_2''(\hat{e}_2) + 2A & \cdots & A \\ \vdots & \vdots & \cdots & \vdots \\ A & A & \cdots & C_L''(\hat{e}_L) + 2A \end{bmatrix},$$

where $A = \dfrac{-1}{\sum_{n=L+1}^{N}(\partial\,\hat{e}_n / \partial\, p)} > 0$.

To have second-order conditions and the stability condition hold at equilibrium emissions $\{\hat{e}_m\}_{m=1}^{L}$, we assume that H is positive definite. By Cramer's rule, we have $\frac{\partial\,\hat{e}_m}{\partial\, t_m} = \frac{-1}{|H|}(-1)^{m+m} H_{m\,m} < 0$, where H_{mm} is the $(m,m)^{\text{th}}$ minor of H. And H_{mm} is positive due to the positive definite nature of H.

***Proof of Equation (25)*:**

By the chain rule, we have $\frac{\partial \hat{e}_m}{\partial t_r} = \left(\frac{\partial \hat{e}_m}{\partial e_r}\right)\left(\frac{\partial \hat{e}_r}{\partial t_r}\right)$ for $m, r = 1,\ldots,L$ and $m \neq r$. Recall firm m's first-order condition is

$$\frac{\partial FC_m}{\partial e_m} = C'(e_m) + p + t_m + \left(\frac{\partial p}{\partial e_m}\right)(e_m - \overline{w}_m) = 0 \quad \text{for} \quad m = 1,\ldots,L.$$

Differentiating this equation with respect to e_r and rearranging it yield

$$\frac{\partial \hat{e}_m}{\partial e_r} = \frac{-(\partial p / \partial e_r)}{C''_m(\hat{e}_m) + 2(\partial p / \partial e_m)} < 0 \quad \text{for} \quad m, r = 1,\ldots,L \quad \text{and} \quad m \neq r.$$

Given $\frac{\partial \hat{e}_r}{\partial t_r} < 0$ in (24), thus we have $\frac{\partial \hat{e}_m}{\partial t_r} > 0$.

***Proof of Equation (29)*:**

The market-clearing condition for the IET system at equilibrium is

$$\sum_{r=1}^{L} \hat{e}_r(t_{1,\ldots,}t_L) + \sum_{n=L+1}^{N} \hat{e}_n(\hat{p}(t_1,\ldots,t_L)) = \sum_{i=1}^{N} \overline{w}_i .$$

Differentiating this equation with respect to t_m and rearranging it yield

$$\frac{\partial \hat{p}}{\partial t_m} - \left(\frac{\partial p}{\partial e_m}\right)\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) = \left(\frac{\partial p}{\partial e_m}\right)\left(\sum_{r \neq m} \frac{\partial \hat{e}_r}{\partial t_m}\right) > 0 \quad \text{by (22) and (25).}$$

***Proof of Theorem 2*:**

From (23) and (27), the impacts of t_m on the country's social cost could be decomposed into a quantity and a price effects. That is,

$$\frac{dSC_m}{d\,t_m} = -\left[t_m + \left(\frac{\partial p}{\partial e_m}\right)(\hat{e}_m - \overline{w}_m)\right]\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) + \left(\frac{\partial \hat{p}}{\partial t_m}\right)(\hat{e}_m - \overline{w}_m) \quad \text{for} \quad m = 1,\ldots,L.$$

Permit buyers ($\hat{e}_m > \overline{w}_m$) will always have a negative price effect. If policy $t_m \geq 0$ is adopted, a positive or zero quantity effect arises due to $\frac{\partial \hat{e}_m}{\partial t_m} < 0$ by (24). Given $\frac{\partial \hat{p}}{\partial t_m} - \left(\frac{\partial p}{\partial e_m}\right)\left(\frac{\partial \hat{e}_m}{\partial t_m}\right) > 0$

by (29), we have $\frac{dSC_m}{d\,t_m} > 0$. It means that the optimal regulation should be $t_m^* = -\infty$, which contradicts with $t_m \geq 0$. Thus, policy $t_m \geq 0$ will never be optimal for price-influencing permit buyers.

In contrast, permit sellers have $\hat{e}_m < \overline{w}_m$, thus have a positive price effect. Adopting policy $t_m \leq 0$ will lead to a negative or zero quantity effect. Accordingly, we have $\frac{dSC_m}{d\,t_m} < 0$. It means that the optimal regulation should be $t_m^* = \infty$, which contradicts with $t_m \leq 0$. Thus, policy $t_m \leq 0$ will never be optimal for price-influencing permit sellers.

References

Böhringer, C., U. Moslener and B. Sturm, 2007. Hot Air for Sale: A Quantitative Assessment of Russia's Near-Term Climate Policy Options. Environmental and Resource Economics, published on line.

Böhringer, C. and A. Löschel, 2003. Market Power and Hot Air in International Emissions Trading: The Impacts of US Withdrawal from the Kyoto Protocol. Applied Economics, 35(6), 651-663.

Brander, J.A. and B.J. Spencer, 1985. Export Subsidies and International Market Share Rivalry. Journal of International Economics, 18, 83-100.

Burniaux, J.-M. and T. P. Truong, 2002. GTAP-E: An Energy-Environmental Version of the GTAP Model. GTAP Technical Paper, No.16.

Ciorba, U., A. Lanza, and F. Pauli, 2001. Kyoto Protocol and Emission Trading: Does the U.S. Make a Difference. FEEM Working Paper No. 90, Electronic access: <http://ssrn.com/abstract=29366>.

Criqui, P., S. Mima, and L. Viguier, 1999. Marginal Abatement Costs of CO_2 Emission Reductions, Geographical Flexibility and Concrete Ceilings: An Assessment Using the POLES Model. Energy Policy, 27, 585-601.

Ellerman, A.D., H.D. Jacoby, and A. Decaux, 1998. The Effects on Developing Countries of the Kyoto Protocol and Carbon Dioxide Emissions Trading. World Bank Policy Research Working Paper No. 2019. Electronic access: <http://ssrn.com/abstract=569250>.

Evans, M., 2003. Emissions Trading in Transition Economies: the Link between International and Domestic Policy. Energy Policy, 31, 879–886.

Kainuma, M., Y. Matsuoka, and T. Mortia, 1999. Analysis of Post-Kyoto Scenarios: The Asian-Pacific Integrated Model. Energy Journal, Special Issue on the Cost of the Kyoto Protocol: A Multi-Model Evaluation, 207-221.

Klepper, G. and S. Peterson, 2005. Trading Hot-Air: The Influence of Permit Allocation Rules, Market Power and the US Withdrawal from the Kyoto Protocol. Environmental and Resource Economics, 32(2), 205-228.

OECD, 1999. Action against Climate Change: The Kyoto Protocol and Beyond, Paris: Organization for Economic Co-operation and Development.

Persson, T.A. and C. Azar, 2003. The Cost of Meeting the Kyoto Protocol: Dealing with the Carbon Surplus in Russia and the Ukraine. Management of Environmental Quality: An International

Journal, 14(4), 488-507.

Rehdanz, K. and R. Tol, 2005. Unilateral Regulation of Bilateral Trade in Greenhouse Gas Emission Permits. Ecological Economics, 54, 397-416.

Rose, A. and B. Stevens, 1993. The Efficiency and Equity of Marketable Permits for CO_2 Emissions. Resource and Energy Economics, 15(1), 117-146.

Sager, J., 2003. An Analysis with the CERT Model of the FSU Market Power in the Carbon Emissions Trading Market. Environmental Modeling and Assessment, 8(3), 219-238.

Westskog, H., 1996. Market Power in a System of Tradeable CO_2 Quotas. The Energy Journal, 17(3), 95-103.

Weyant, J. (Ed.), 1999. The Cost of the Kyoto Protocol: A Multi-Model Evaluation. The Energy Journal, special issue.

Table 1. Data Used in the Numerical Analysis

Countries/Regions	$\overline{b}_i$ (MtC) [a]	$\overline{w}_i$ (MtC)	α_i
Russia	372.53	420.47	0.97
The EU	911.16	707.06	0.64
The US	1,499.78	965.86	0.18
Japan	337.22	229.98	1.58

Source: $\overline{b}_i$ and $\overline{w}_i$ are taken from the GTAP-E model, and α_i are estimated by the same model.
a. MtC: million tons of carbon.

Table 2. Summary of Our Simulation Scenarios

Scenario Type	Market Structures	Governments' Regulations	Number of Scenarios	Countries with Market Power	Price-Taking Countries
I	Perfect Competition	No	1		Russia, EU, US, Japan
II	Perfect Competition	Yes	2		Russia, EU, US, Japan
III	Imperfect Competition	Yes	3	Russia	EU, US, Japan
		Yes	4	EU	Russia, US, Japan
		Yes	5	US	Russia, EU, Japan
		Yes	6	Japan	Russia, EU, US
		Yes	7	Russia, EU	US, Japan
		Yes	8	Russia, US	EU, Japan
		Yes	9	Russia, Japan	EU, US
		Yes	10	EU, US	Russia, Japan
		Yes	11	EU, Japan	Russia, US
		Yes	12	US, Japan	Russia, EU
		Yes	13	Russia, EU, US	Japan
		Yes	14	Russia, EU, Japan	US
		Yes	15	Russia, US, Japan	EU
		Yes	16	EU, US, Japan	Russia

Table 3. Equilibrium Permit Prices Under Various Scenarios

Scenarios		Countries with Market Power	Permit Price (US$/tC)
1	Globally Cost-Effective Case	None	90.79
2	Perfect Competition	None	87.32
3	Imperfect Competition	Russia	92.71
4	Imperfect Competition	EU	89.49
5	Imperfect Competition	US	87.24
6	Imperfect Competition	Japan	90.38
7	Imperfect Competition	Russia, EU	91.50
8	Imperfect Competition	Russia, US	93.03
9	Imperfect Competition	Russia, Japan	92.31
10	Imperfect Competition	EU, US	81.23
11	Imperfect Competition	EU, Japan	89.03
12	Imperfect Competition	US, Japan	85.88
13	Imperfect Competition	Russia, EU, US	90.87
14	Imperfect Competition	Russia, EU, Japan	91.06
15	Imperfect Competition	Russia, US, Japan	92.16
16	Imperfect Competition	EU, US, Japan	76.45

Table 4. Equilibria, Social Costs and Efficiency Losses in the Globally Cost-Effective Case and the Competitive IET System with Governments' Regulations (Scenarios 1 & 2)

	Russia	The EU	The US	Japan	Sum
Scenario 1 Globally Cost-Effective Case					
Optimal Emissions (MtC)	278.93	769.30	995.39	279.76	
Permit Purchases (MtC)	-141.54	62.24	29.53	49.77	
Social Costs (millions of US dollars)	-8,601.57	12,090.58	25,578.04	7,127.51	36,194.57
Scenario 2 Perfect Competition with Governments' Regulations					
Optimal Emissions (MtC)	298.70	762.68	983.78	278.21	
Permit Purchases (MtC)	-121.77	55.62	17.93	48.22	
Optimal Regulations (US$/tC)	-15.71	7.70	5.56	5.92	
Social Costs (millions of US dollars)	-7,989.70	11,911.71	25,527.99	6,962.18	36,412.19
Efficiency Losses (millions of US dollars)	611.87	-178.86	-50.05	-165.33	217.62

Table 5 Equilibria, Social Costs and Efficiency Losses in the Imperfectly Competitive IET Systems with One Price-influencing Player (Scenarios 3-6)

	Russia	The EU	The US	Japan	Sum
Scenario 3 Price-influencing Player: Russia					
Optimal Emissions (MtC)	293.80	766.30	984.73	278.54	
Permit Purchases (MtC)	-126.67	59.24	18.87	48.56	
Optimal Regulations (US$/tC)	0.00	0.00	0.00	0.00	
Social Costs (millions of US dollars)	-8,737.34	12,207.11	25,624.47	7,221.84	36,316.07
Efficiency Losses (millions of US dollars)	-135.77	116.53	46.42	94.32	121.51
Scenario 4 Price-influencing Player: The EU					
Optimal Emissions (MtC)	280.27	759.90	1,002.62	280.58	
Permit Purchases (MtC)	-140.20	52.84	36.76	50.60	
Optimal Regulations (US$/tC)	0.00	0.00	0.00	0.00	
Social Costs (millions of US dollars)	-8,418.13	12,050.05	25,534.88	7,062.16	36,228.97
Efficiency Losses (millions of US dollars)	183.44	-40.52	-43.16	-65.35	34.40
Scenario 5 Price-influencing Player: The US					
Optimal Emissions (MtC)	282.59	774.84	983.94	282.00	
Permit Purchases (MtC)	-137.88	67.78	18.09	52.02	
Optimal Regulations (US$/tC)	0.00	0.00	0.00	0.00	
Social Costs (millions of US dollars)	-8,106.11	11,860.04	25,525.69	6,947.02	36,226.64
Efficiency Losses (millions of US dollars)	495.46	-230.54	-52.36	-180.49	32.07
Scenario 6 Price-influencing Player: Japan					
Optimal Emissions (MtC)	279.35	769.94	997.67	276.41	
Permit Purchases (MtC)	-141.12	62.88	31.81	46.43	
Optimal Regulations (US$/tC)	0.00	0.00	0.00	0.00	
Social Costs (millions of US dollars)	-8,543.54	12,064.89	25,565.45	7,117.29	36,204.10
Efficiency Losses (millions of US dollars)	58.03	-25.69	-12.59	-10.22	9.53

Table 6 Equilibria, Social Costs and Efficiency Losses in the Imperfectly Competitive IET Systems with Two Price-influencing Players (Scenarios 7-12)

	Russia	The EU	The US	Japan	Sum
Scenario 7 Price-influencing Players: Russia and the EU					
Optimal Emissions (MtC)	295.52	757.12	991.42	279.31	
Permit Purchases (MtC)	-124.95	50.06	25.56	49.32	
Optimal Regulations (US$/tC)	3.39	-1.01	0.00	0.00	
Social Costs (millions of US dollars)	-8,557.21	12,173.72	25,597.69	7,162.84	36,377.03
Efficiency Losses (millions of US dollars)	44.36	83.14	19.64	35.33	182.47
Efficiency Losses due to Market Power	69.96	104.75	24.85	45.59	245.14
Efficiency Losses due to Regulations	-25.60	-21.61	-5.21	-10.26	-62.67
Scenario 8 Price-influencing Players: Russia and the US					
Optimal Emissions (MtC)	307.52	765.80	971.71	278.34	
Permit Purchases (MtC)	-112.95	58.74	5.86	48.36	
Optimal Regulations (US$/tC)	21.48	0.00	-0.65	0.00	
Social Costs (millions of US dollars)	-8,458.27	12,226.08	25,641.59	7,237.42	36,646.82
Efficiency Losses (millions of US dollars)	143.30	135.50	63.55	109.91	452.25
Efficiency Losses due to Market Power	294.58	312.37	78.46	258.74	944.16
Efficiency Losses due to Regulations	-151.28	-176.87	-14.91	-148.83	-491.91

Table 6 (Cont'd)

	Russia	The EU	The US	Japan	Sum
Scenario 9 Price-influencing Players: Russia and Japan					
Optimal Emissions (MtC)	294.27	766.93	986.95	275.23	
Permit Purchases (MtC)	-126.21	59.87	21.09	45.24	
Optimal Regulations (US$/tC)	1.34	0.00	0.00	-0.71	
Social Costs (millions of US dollars)	-8,679.12	12,183.26	25,616.47	7,212.42	36,333.03
Efficiency Losses (millions of US dollars)	-77.55	92.68	38.42	84.91	138.46
Efficiency Losses due to Market Power	-69.98	98.15	40.33	91.81	160.32
Efficiency Losses due to Regulations	-7.57	-5.47	-1.91	-6.91	-21.86
Scenario 10 Price-influencing Players: The EU and the US					
Optimal Emissions (MtC)	288.79	757.48	991.29	285.81	
Permit Purchases (MtC)	-131.68	50.42	25.43	55.82	
Optimal Regulations (US$/tC)	0.00	-13.18	-4.99	0.00	
Social Costs (millions of US dollars)	-7,295.43	11,653.22	25,336.37	6,622.70	36,316.86
Efficiency Losses (millions of US dollars)	1,306.14	-437.36	-241.67	-504.81	122.30
Efficiency Losses due to Market Power	1,892.87	-499.72	-348.42	-764.55	280.18
Efficiency Losses due to Regulations	-586.73	62.36	106.75	259.74	-157.88

Table 6 (Cont'd)

	Russia	The EU	The US	Japan	Sum
Scenario 11 Price-influencing Players: The EU and Japan					
Optimal Emissions (MtC)	280.74	760.41	1,005.15	277.07	
Permit Purchases (MtC)	-139.73	53.35	39.29	47.09	
Optimal Regulations (US$/tC)	0.00	-0.65	0.00	-1.15	
Social Costs (millions of US dollars)	-8,354.48	12,022.14	25,517.59	7,050.48	36,235.73
Efficiency Losses (millions of US dollars)	247.09	-68.44	-60.45	-77.03	41.16
Efficiency Losses due to Market Power	271.81	-73.19	-67.50	-81.65	49.47
Efficiency Losses due to Regulations	-24.72	4.75	7.05	4.62	-8.31
Scenario 12 Price-influencing Players: The US and Japan					
Optimal Emissions (MtC)	284.00	776.98	986.23	276.17	
Permit Purchases (MtC)	-136.47	69.92	20.37	46.18	
Optimal Regulations (US$/tC)	0.00	0.00	-1.29	-7.22	
Social Costs (millions of US dollars)	-7,918.22	11,765.73	25,485.48	6,910.67	36,243.66
Efficiency Losses (millions of US dollars)	683.35	-324.84	-92.57	-216.84	49.09
Efficiency Losses due to Market Power	849.37	-411.47	-116.55	-229.91	91.45
Efficiency Losses due to Regulations	-166.02	86.63	23.98	13.07	-42.36

Table 7 Equilibria, Social Costs and Efficiency Losses in the Imperfectly Competitive IET Systems with Three Price-influencing Players (Scenarios 13-16)

	Russia	The EU	The US	Japan	Sum
Scenario 13 Price-influencing Players: Russia, the EU, and the US					
Optimal Emissions (MtC)	333.28	738.42	971.96	279.71	
Permit Purchases (MtC)	-87.19	31.36	6.11	49.72	
Optimal Regulations (US$/tC)	84.97	-29.87	-5.51	0.00	
Social Costs (millions of US dollars)	-7,176.02	12,398.16	25,627.90	7,131.44	37,981.48
Efficiency Losses (millions of US dollars)	1,425.54	307.59	49.85	3.93	1,786.92
Efficiency Losses due to Market Power	2,987.61	855.45	73.77	389.85	4,306.68
Efficiency Losses due to Regulations	-1,562.07	-547.86	-23.92	-385.92	-2,519.76
Scenario 14 Price-influencing Players: Russia, the EU, and Japan					
Optimal Emissions (MtC)	296.11	757.59	993.88	275.79	
Permit Purchases (MtC)	-124.36	50.53	28.02	45.81	
Optimal Regulations (US$/tC)	5.45	-1.87	0.00	-2.25	
Social Costs (millions of US dollars)	-8,492.13	12,148.17	25,585.84	7,152.34	36,394.23
Efficiency Losses (millions of US dollars)	109.44	57.59	7.80	24.83	199.66
Efficiency Losses due to Market Power	180.77	84.14	11.75	40.82	317.47
Efficiency Losses due to Regulations	-71.33	-26.55	-3.95	-15.99	-117.81

Table 7 (Cont'd)

	Russia	The EU	The US	Japan	Sum
Scenario 15 Price-influencing Players: Russia, the US, and Japan					
Optimal Emissions (MtC)	312.09	767.16	972.91	271.22	
Permit Purchases (MtC)	-108.39	60.10	7.05	41.24	
Optimal Regulations (US$/tC)	35.84	0.00	-1.84	-14.28	
Social Costs (millions of US dollars)	-8,217.06	12,174.44	25,633.18	7,241.63	36,832.19
Efficiency Losses (millions of US dollars)	384.50	83.86	55.14	114.12	637.62
Efficiency Losses due to Market Power	941.40	286.03	78.28	379.16	1,684.87
Efficiency Losses due to Regulations	-556.90	-202.17	-23.14	-265.04	-1,047.25
Scenario 16 Price-influencing Players: The EU, the US, and Japan					
Optimal Emissions (MtC)	293.72	757.40	995.23	277.03	
Permit Purchases (MtC)	-126.76	50.34	29.37	47.04	
Optimal Regulations (US$/tC)	0.00	-26.87	-14.12	-26.98	
Social Costs (millions of US dollars)	-6,677.89	11,414.04	25,156.84	6,458.84	36,351.84
Efficiency Losses (millions of US dollars)	1,923.68	-676.54	-421.20	-668.67	157.27
Efficiency Losses due to Market Power	3,549.39	-1,044.58	-806.57	-1,116.08	582.14
Efficiency Losses due to Regulations	-1,625.71	368.04	385.37	447.41	-424.87

Establishing A Finance and Taxation Guarantee System for Environmental Basic Public Services in China

Li Na, Li Hongxiang, Ge Chazhong, Wu Shunze

Abstract: This paper first describes the extensive demand of environmental basic public service supply and its huge gap between rural and urban areas and regions. Then it analyzes the reason that the existence of the gap is largely attributable to the uneven level of economic development and insufficient environmental investment. Finally, with reference to the financial and tax system in medical care, education and other public services already achieved in China, it proposes the concept of using public finance to resolve environmental equality welfare and further proposes to realize the public financial and tax system for equalization of environmental public service in China.

Key words:

1. Definition and content of environmental basic public service

1.1 Concept of basic public service

Clearly defining the concept of basic public service is the basis for this study. However, presently public service is not clearly defined and as a result the study subject of basic public service is not specific and its scope is uncertain. Before defining the concept of public service, we introduce the concept of public product. In accordance with the classical definition given by Samuelson in "The Pure Theory of Public Expenditure", public product is the product or labor whose consumption by a person will not result in the other people's reduction of this product or labor. Public product has three typical characteristics: effectiveness indivisibility, consumption noncompetitiveness and benefit nonexcludability.① Effectiveness indivisibility. Public service is oriented to the whole public and its effectiveness is shared by all social members and is not divisible or limited to separate enjoyment by an individual or a group.② Consumption noncompetitiveness. Use of public service by a group does not affect or reject the use of another group's use of the same public service, i.e.

marginal production cost and marginal congestion cost of public service are zero. Benefit nonexcludability. Technically, the individual or group that refuses to pay for public service can not be precluded from the benefit scope of public service and nobody can reject the other people's consumption of this public service or refuse his own consumption of this public service. This study thinks that public service is a concept essentially equivalent to public product but the scope of public service should be more extensive, not only including pure public service, the service that everyone consumes without affecting other people's consumption, but also including partial quasi-public service, the service that only has one of the three typical characteristics of public service but has greater outflow. Therefore, public service is the pure public service and quasi-public service provided or mainly provided by the government.

After the public service is defined, we further define the concept of public service. This study thinks that basic public service is the minimum standard public service that is closely related to the people's livelihood and plays a fundamental role in the existence and development of social public in a certain development stage. It includes two levels: minimum scope and minimum standard. Minimum scope means that basic public service is the public service that covers the minimum scope and boundary in a certain development stage and, depending on China's actual national condition, economic development condition and present issues that are mostly cared by the people and masses and need to be resolved urgently, should be included with minimum social security, public health, compulsory education and environmental protection in the scope of basic public service. Minimum standard means that basic public service is a low level public service and a generalized and security-oriented service while high grade service is not basic public service and not provided by the government. For example, the government is responsible for 9-year compulsory education but does not ensure that everyone receives higher education; the government provides minimum living security fund but does not ensure that you live without worry about food and clothes; the government provides basic public health projects but is not responsible for high grade medical treatment projects.

1.2 Concept and scope of environmental basic public service

Based on our definition of basic public service, we think that environmental basic service is the minimum scope and minimum standard public service that is provided by the government and guarantees the public basic environmental rights and interests in a certain development stage. It mainly has two meanings: firstly, environmental basic public service should safeguard the citizens' most basic environmental rights and interests and secondly, it refers to minimum scope and minimum standard and is a dynamic and staged concept.

As we know, the environmental basic public services is a public service provided by the government, and closely related to the environmental right of the public.. Therefore, the scientific and rational understanding of the need of the basic environmental service from the public is necessary in order to identify the scope for the environmental basic public service. The service is divided into four aspects (different priority areas at different stages): (1)environmental basic service,including the services of providing ① sewage treatment；②wastes cleaning, transfer and safe disposal ;③waste gas and particulates cleaning；④environmental information, mainly to provide the public with the channels for right to know about environment.

2. Development status quo and gap of environmental basic public service in China

2.1 Investment in environmental basic public service as a whole is insufficient

After many years of reform and development, China’s environmental investment has been increasing year after year and China has set up dedicated environmental budget expenditure subject and established central special fund for environmental protection, central financial special fund for emission reduction of major pollutants, funds for “reward replacing subsidy” for the associated pipe network of urban wastewater treatment facilities and central special fund for rural environmental protection; pollutant discharge fee keeps increasing and plays an important role in the national energy saving, emission reduction and enterprise technical innovation. In 2008, China invested 449.03 billion Yuan in environmental pollution abatement, being 1.49% gross domestic product of the year. Nevertheless, China now has a slightly larger caliber for environmental protection investment and some local governments, when making statistics of environmental protection investment, include the operation cost of environmental protection facilities, ecological protection and construction investment, environmental management capacity building and environmental management service charge as well as investment in projects with environmental benefit, cleaner production, and investment in construction of environmentally friendly product production projects into environmental protection investment caliber. This is especially manifested by fuel gas and central heating supply in the investment for urban environmental infrastructure construction and at the same time, the existing environmental protection investment efficiency needs to be enhanced.

2.2 Environmental basic public service differs between regions and urban and rural areas to a different extent

Environmental basic public service differs greatly between regions. For urban wastewater treatment, for example, urban domestic wastewater treatment rate is very different in different provinces. By 2008, urban domestic wastewater treatment rate was over 70% in Beijing, Tianjin, Shanghai, Zhejiang, Shandong and Chongqing while it was below 30% in Hunan, Guangxi and Guizhou; Shanghai had the highest treatment rate which was 3.5times that in Guangxi. At city level, of the 113 major cities in China, wastewater treatment rate exceeded 80% in 25 cities including Beijing, Shanghai, Nanjing and Wuhan while it was below 40% in 23 major cities including Guiyang, Shantou and Shaoguan. Municipal solid waste disposal rate exceeded 90% in Beijing, Tianjin and Jiangsu but below 40% in Jilin, Heilongjiang and Gansu.

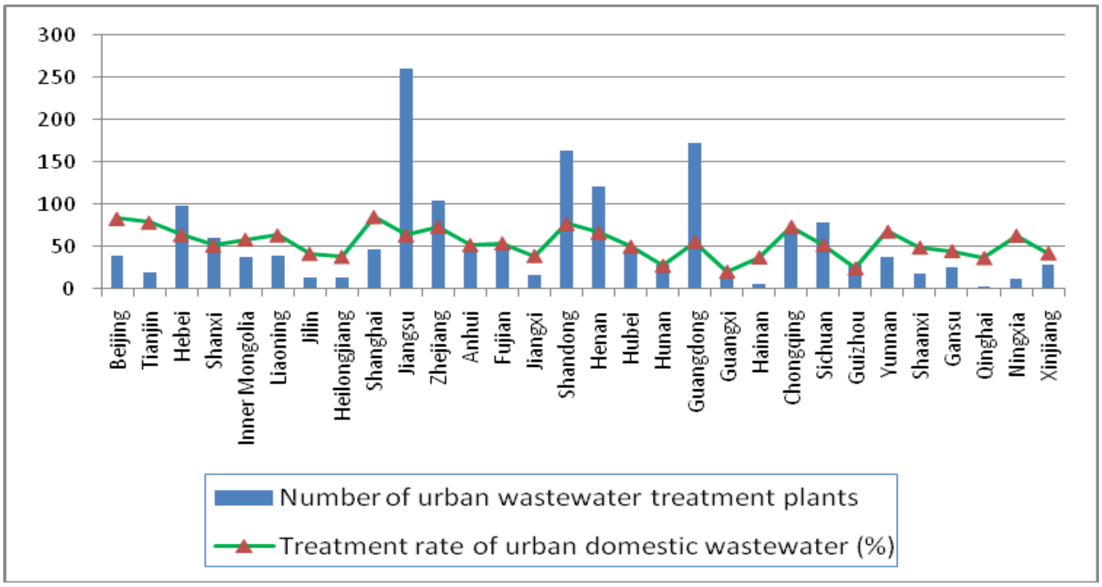


Figure 2-1 Number of Wastewater Treatment Plants and Treatment Rate of Urban Domestic Wastewater in Provinces (Cities) in China in 2008

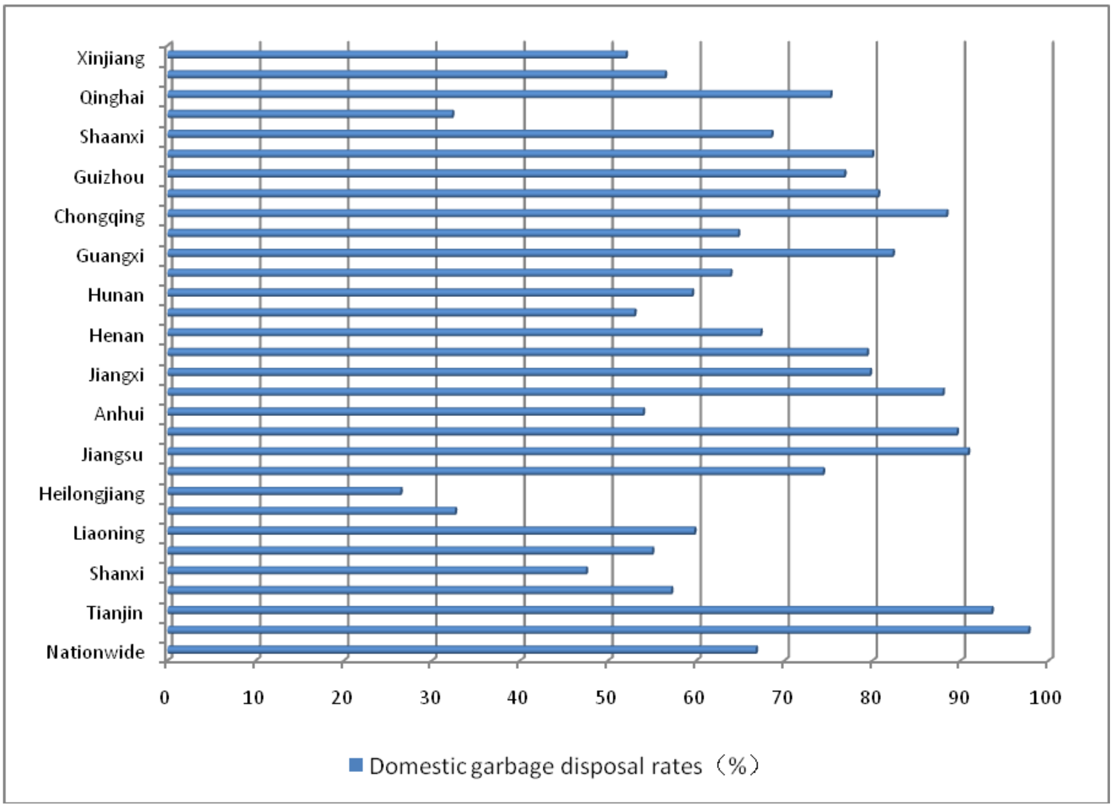


Figure2-2 Harmless Disposal Rate of Municipal Solid Waste in Provinces (Cities) in China in 2008

Environmental basic service differs greatly between urban and rural areas. Due to causes in economic condition, technical level and management mode, wastewater treatment and solid waste treatment facilities in China are mainly in cities while wastewater treatment work in small cities and towns and rural areas is progressing very slowly. According to the "Statistic Bulletin for Construction of Cities, Country Towns, Villages and Towns in 2007", by the end of 2007, there had been 1,635 counties in China and 323 wastewater treatment plants in county towns. Daily wastewater treatment capacity was 7.27 billion m3, drainage pipe was 76,800km2, annual total wastewater treatment capacity in county towns was 1,360 million m3 and county town wastewater treatment rate was 22.6% where centralized treatment rate of wastewater treatment plants was 17.6%. In the same period, there had been 655 cities of administrative establishment in China and 883 wastewater treatment plants in cities. Daily wastewater treatment capacity was 71.38 million m3, drainage pipe was 292,000km, annual total wastewater treatment capacity in cities was 22.7 billion m3 and city wastewater treatment rate was 62.8% where centralized treatment rate of wastewater treatment plants was 49.6%. Wastewater treatment rate in county towns was only 1/3 that in cities and length of drainage pipe network was less than 1/4 that in cities. In addition, a great deal of urban pollution is transferred to rural areas. There are many historically accumulated problems in rural areas and in some places, peasants often become an environmental vulnerable group.

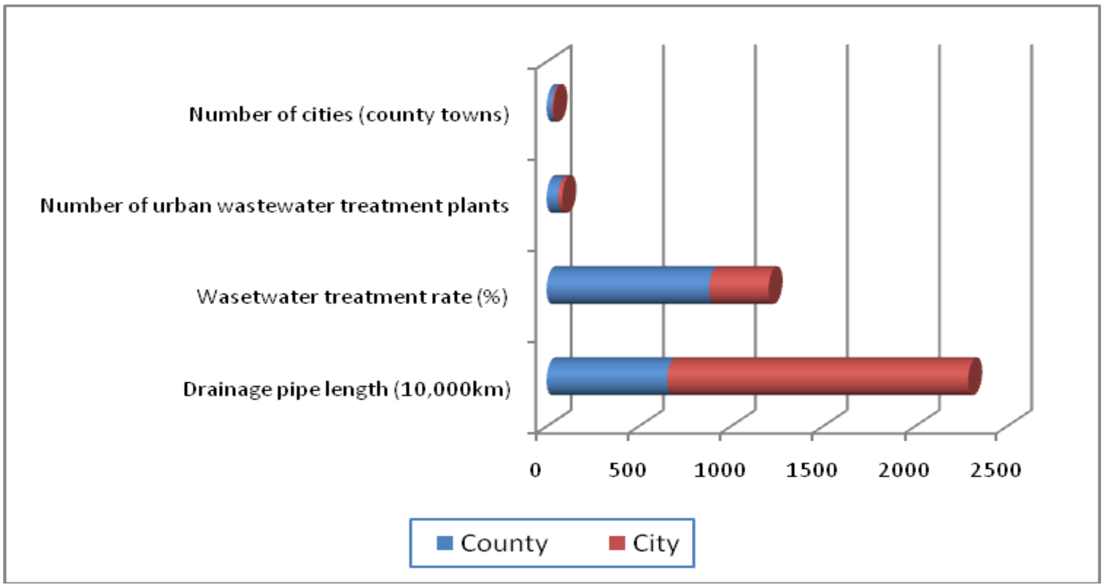


Figure 2-3 Comparison of Wastewater Treatment between Cities and County Towns in China in 2007

2.3 The public finance system for promoting the development of basic public service is not available

Public nature is the soul of public finance. For a long time, China has been attaching importance to rapid economic development and financial investment has been focusing on the economic construction field, which has become the "short leg" phenomenon in such basic public service as medical care, education and environmental protection . Although financial expenditure has exited the general and competitive fields and changed to the public product and public service fields such as the "issues concerning agriculture, countryside and farmers", education, science and technology, medical care and health, employment, social security and environmental protection since the public financial policy framework was established in 1998, economic construction expenditure in 2006 was 26.6% of the total expenditure1. Therefore, in order to change the present huge gap in basic public service, it is

1 Zhao Yunqi, Change of National Financial Revenue and Expenditure in the Past 60 Years since the Founding of New China. Contemporary China History Studies, 2009(5)

necessary to all out adjust financial expenditure structure, pay more attention to the people's livelihood and invest finance in the long-term "short leg" public service industries such as compulsory education, basic medical treatment and public health, basic social security and environmental protection and invest more in the regions where basic public service is weak such as western underdeveloped regions and rural areas. Public finance shall promote and safeguard the construction of primary functional zones, increase the ecological compensation transfer payment scale for development-restricted regions and development-prohibited regions and ensure that the residents in these regions enjoy equalized basic public service.

3. Social demand and economic factor behind the gap

3.1 Environmental protection now has become one of the biggest people's livelihoods in China

Environmental protection has become a hot issue of the people's livelihood ranking in the top five before public safety, education and medical care. The right of existence and the right of development are the citizens' most basic human rights and enabling the common people to drink clean water, breath clean air and eat safe food is the basic requirement for the people's livelihood. However, due to extensive economic growth mode and heavy environmental pollution in China, the people and the masses' right of life and right to health can not be effectively guaranteed. "China Water Resources Bulletin 2008" indicates that in 2008, the 3,219 water function zones for monitoring and evaluation were evaluated for the water quality management objective for water function zones and the up-to-standard rate of water function zones in the whole year was only 42.9%. Up-to-standard rate of Grade 1 water function zones (excluding development and utilization zones) was 53.2% and up-to-standard rate of Grade 2 water function zones was only 36.7%. According to water quality monitoring for 641 underground water monitoring wells, the number of Class I~III monitoring wells whose water is suitable for drinking was only 26.2% total of monitoring wells. The "State of China Environment in 2009" indicates that urban ambient air quality could not reach Grade 2 standard in 20.4% cities at and above prefecture level. The current air quality evaluation indicators in China now only include sulfur dioxide, nitrogen dioxide and inhalable particulate matter and "standard revision frequency is long, pollution indicators are not complete and limits as a whole are lower" compared with the standards of the United States and World Health Organization. In addition, pollution by heavy metals like cadmium and lead greatly is threatening the people's health. In 2009, the Ministry of Environmental Protection received 12 cases for heavy metal and metalloid pollution that resulted in 4,305 persons' blood lead and 182 persons' cadmium exceeding the standard. Environmental protection is a thing that is done in the present time and benefits later generations. It is not only related to the existence and happiness and benefit of the people in the contemporary era but also related to the vital happiness and benefit of our descendents.

3.2 The financial pattern of "financial rights above duties and responsibilities" makes it more difficult for local governments to provide environmental basic public service

Finance is an important means that the government uses to provide public service and clear division of duties and responsibilities is the basis for dividing financial expenditure systems and the precondition for realizing financial allocation equalization. Basic public service equalization can be well realized only when duties and responsibilities match with financial rights and expenditure responsibilities assumed by government at all levels are proportional to their financial revenues. After the reform of tax sharing system in 1994, the weight of duties and responsibilities has risen and the weight of financial rights has fallen significantly between government levels in China. Division of responsibilities between central and local governments in our constitution is too general and responsibilities between governments are not clearly defined. As a result, higher level government issues some unclearly defined responsibilities to lower level government and some legal duties and responsibilities of higher level government are also decomposed to lower level government through responsibility assessment and one-vote veto. Grassroots governments assume excessive expenditure responsibilities in regional public service such as basic education and medical care and health. Contrary to the level-by-level issuance of the duties and responsibilities, higher level government collects or shares the taxes that are in large amounts and easy to collect and leaves to local governments the taxes that are distributed, in small amounts and difficult to collect. Basically, local governments lack stable and large-amount taxes. As financial rights move up level by level, taxes of higher level government grow fast and taxes of lower level government grow slowly and lower level government has financial difficulties. "China Statistical Yearbook 2009" shows that the national financial revenue in 2008 was 6,133.035 billion Yuan including 3,268.056 billion Yuan for central and 2,864.979 billion Yuan for local, and central to local revenue ratio was 53.3% : 46.7% while expenditure ratio in the same year was 21.3% : 78.7%. This system where duties and responsibilities are under financial rights and duties and responsibilities and financial rights are seriously unmatched longitudinally, has increased the financial difficulties of local governments such as counties and townships and prevented the lower level governments and especially the grassroots governments in backward regions from having the fiscal capacity to provide nationally equal environmental basic service.

3.3 China does not have a scientific and long term transfer payment system

Transfer payment is the foremost means to promote equalization of environmental basic public service overseas. To ensure that all provinces (states) are able to provide equalized basic public service, federal governments of all countries promise to ensure the equalization of provincial (state) governments' fiscal capacity. The Constitution of Canada provides that in order to realize equalization of basic public service, federal government should ensure financial equalization in all provinces and implement longitudinal transfer payment for all provinces. Germany realizes financial balance of governments in all places by combining longitudinal equalization with horizontal equalization to ensure an approximately equal public service is provided nationwide. However, the present transfer payment system in China is not very complete and it includes two parts: tax refund and transfer payment, and the latter includes financial transfer payment (including general transfer payment) and special transfer payment. In 2008 the central government granted 2,299.076 billion Yuan as tax refund and transfer payment to local government, including 428.216 billion Yuan tax refund, up 3.9%, 874.621 billion Yuan as financial transfer payment (including general transfer payment) and 996.239 billion Yuan as special transfer payment. But tax refund safeguards the vested interest to a large extent and the general transfer payment for maintaining basic public service equalization is relatively insufficient, which was 351.501 billion Yuan in 2008, only accounting for 15.29% total amount of tax refund and transfer payment granted by central to local. This has enlarged the original gap of regional financial capacity between regions and between urban and rural areas and further enhanced the non-equality of regional public service. Tax refund and income tax base return makes the rich become richer and the poor becomes poorer and increases the inequality of environmental basic service between regions.

4 The opportunities and conditions for the currently proposed basic insurance of the services

4.1 Rapid growth of financial revenue and adequate national strength

The financial revenue in China has been growing significantly in the last ten years or more, which has been gowing a little bit faster than the GDP growth rate. The financial revenue growth rate maintained at the level between 14% and 20% from 1994 to 2003. While the GDP growth rate remained at around 8% during this period of time. The financial revenue maintained at 20% or above since the adjustment of the national fiscal policy in 2004, with the GDP growth rate of 10% for the same period of time. Influenced by the macro policy, several important nodal points are:（1）The proactive fiscal policy was initiated in 1998[2]，tax cut, demand expansion, tax growth dropped below 15%, but then rapid resume of growth momentum, with peak value of 22% in 2004;（2）The transformation to stable fiscal policy implemented in 2004 to avoid “overheated ” economy and rapid inflation[3]， with the main contents” controlling deficit, promoting the reform, adusting the structure ,increasing income and reducing expenditure”. The financial revenue growth rate remained at 20% or above in the following years, with the growth rate of 32% in 2007, hitting the record high since 1994;（3）The financial revenue dropped slightly in 2008, affected by financial crisis, but still higher than 2003 level.

【see diagram 4-1 for details 】。

[2] Proactive fiscal policy: is an expanding fiscal policy theoretically, a fiscal policy implemented to avoid economic recession through tax cut or expenditure increase and expanding total demand.积极的财政政策：即理论上的扩张性财政政策，指财政通过减少税费或增加支出，扩张总需求，避免经济衰退的情况下实施的一种财政政策。

[3] Stable fiscal policy: is a neutral fiscal policy theoretically, which neither expands nor contracts the total demand,the status between expanding and contracting fiscal policy. The policy is implemented when the total economic volumn is basically balanced, with stable price and prominent structural problems .稳健的财政政策：即理论上的中性财政，指财政政策对总需求既不扩张也不收缩的情形，是介于扩张性和紧缩性财政政策之间的一种中间状态，是在经济总量基本平衡，物价比较稳定、结构性问题相对突出情况下施行的一种财政政策。

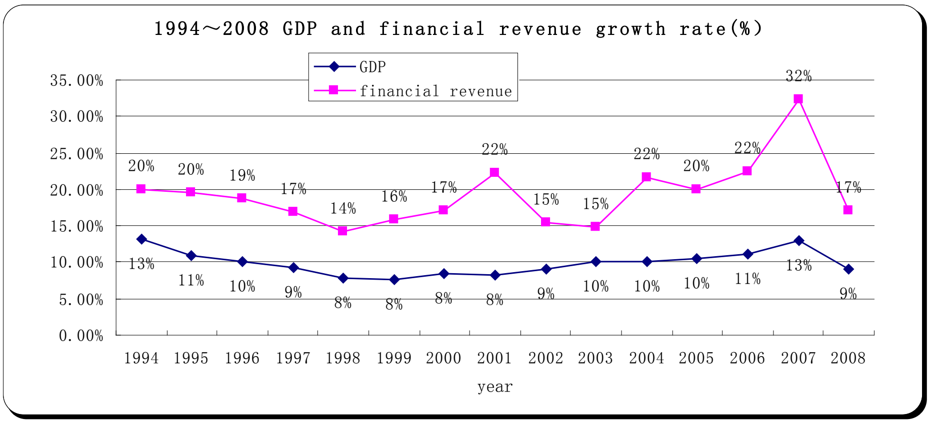


Diagram 4-1 GDP and financial revenue growth rate 1994~2008

Source: Statistical Yearbook of China, 2007; Finance Yearbook of China, 2009

Note：the main sources for the financial revenue are various taxes, with the non taxation revenue accounting for 5.2% in 2008

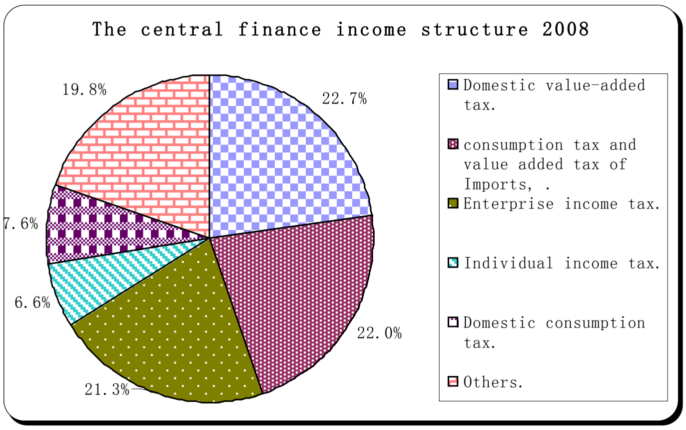
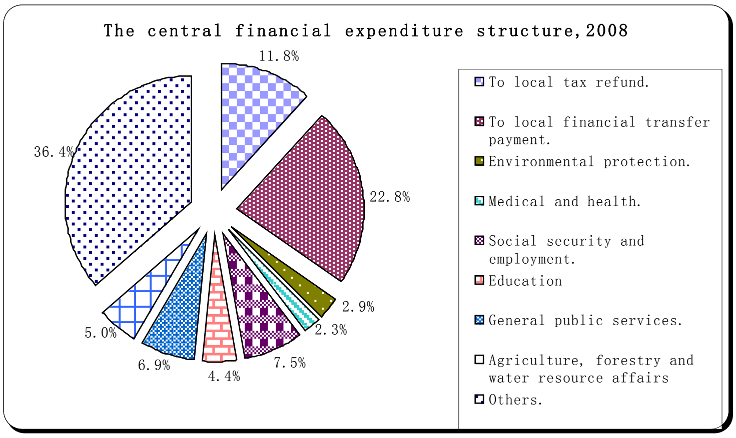


Diagram 4-2 Structure of central financial revenue in 2008

Source: Finance Yearbook of China, 2009

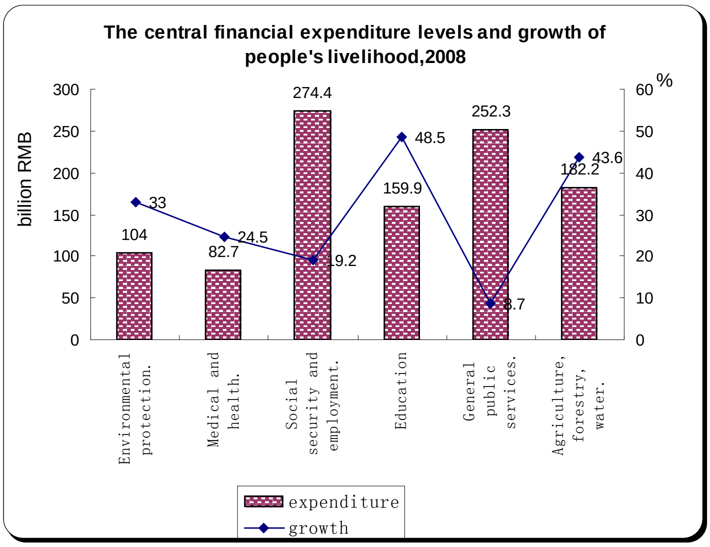
4.2 Certain achievements obtained and experiences accumulated in social welfare insurance

The concept of public fiscal policy was put forward by China in 1998 with the reform of the fiscal policy system, which fiscal model mainly characterized by: government as the main function body, compensating for the market imbalance as the prerequisites, meeting the public demand as the basic point and providing the social public products as the main content (Su Ming, 2008). The social welfare insurance system is gradually established after ten years' development: implementation of the basic retirement insurance, unemployment insurance, deepening the reform in medical health system, addressing the issue of "difficult and expensive seeing doctors ", improving the social aid system etc. the expenditure in people's livelihood increased year by year, with the growth rate of 20% or more. The ratio change is not significant, but the expenditure increased at the rate of 27.6%. The total expenditure on people's livelihood totaled 560.364 billion Yuan, including the expenses for medical health, education, employment, social insurance, and low-income housing etc.(see diagram 4-3，4-4 for the detailed ratio**)**



Source: Finance Yearbook of China, 2009

Diagram 4-3 2The structure for the central financial expenditure in 2008



Source: Finance Yearbook of China, 2009

Diagram 4-4 The central financial expenditure levels and growth of people's livelihood in 2008

4.3 The construction of the sewage and wastes treatment plants in cities and counties formed a certain scale

（1）Sewage treatment plant

The actual annual treatment volume of the sewage at sewage treatment plants reached 21.031 billion ton, among which the city and county sewage treatment plants treated 19.441 billion ton, accounting for 92.5%; industrial wastes treatment plants (facilities) treated (excluding the amount of sewage treated from internal treatment facilities of enterprises) 1.29 billion ton， accounting for 6.1%; Other sewage treatment plants (facilities) treated 300 million ton, accounting for 1.4%.

The reduction amount of major pollutants: COD: 5.9058 million ton, TN: 288,200 ton, TP :45,300 ton, ammonia nitrate : 376,200 ton, oil type products :42,900 ton, volatile phenol :463.81 ton. The reduction of heavy metals at central treatment of industrial sewage :1200 ton.

（2）Wastes treatment plants (sites)

Landfill of wastes were 153 million ton (accounting for 90.5% of the total national treatment capacity), among which: sound landfill :85.9292 million ton, simple landfill: 67.2682 million ton. Altogether 375 million cubic meter of wastes were handled at the sound landfill sites, accounting for 20.9% of the designed capacity; 429 million cubic meter of wastes were managed at simple landfill sites, accounting for 30.5% of the designed capacity.

The wastes incineration treatment volume was 13.7080 million ton, accounting for 8.1% of the national total wastes treatment capacity.

（3）Hazardous wastes disposal plants

The designed disposal capacity at hazardous wastes disposal plants were 11.300 ton/day, with the actual annual disposal amount of 1.1742 million ton; among which the incineration disposal volume was 503,700 ton, accounting for 42.9% of the national total hazardous wastes disposal capacity; the disposal volume at landfill sites was 315,000 ton, accounting for 26.8%.[4]

[4]Based on the [The First Report on the Survey of the Naitonal Pollution Sources](2007 data)根据 2010 年发布的《第一次全国污染源普查状况公报》（2007 年数据）

The urban sewage treatment rate increased steadily, reached 64% in 2008 from 42.4% in 2003; The sound treatment rate increased to 65% from 50.8% in 2003. 【see diagram 4-5 for details】

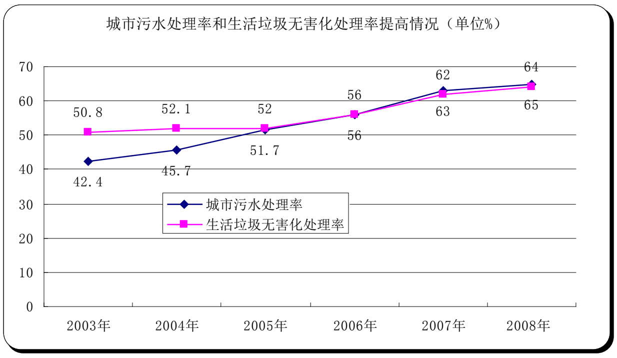


Diagram 4-5 The increase of urban sewage treatment rate and sound treatment of domestic wastes

Source: Finance Yearbook of China, 2009

4.4 Non-point source pollution in rural areas has become the challenge in pollution control

The water pollutants discharge from non-point source pollution in rural areas accounted for more than 50% of the total discharge. Based on the [The First Report on the Survey of the National Pollution Sources] (2007 data), the discharge (loss) status of main water pollutants from agricultural source (excluding typical rural domestic source, same with the following content) are as follows: COD: 13.2409 million ton, accounting for 43.7% of the total discharge, TN :2.7046 million ton, accounting for 57.2%, TP: 284,700 ton, accounting for 67.3%, and for heavy metals, copper:452.09 ton, zinc: 4862.58 ton etc. The big contributers come from husbandry breeding industry, COD: 12.6826 million ton, TN :1.0248 million ton, TP :160,400 ton, copper: 2397.23 ton, and zinc: 4756 .94 ton.

The decentralization of rural non-point source made it difficult to control and regulate. Currently, the non-point source discharge is the major cause for the worsening water quality and soil contamination.

5 Plan for the financial mechanism for the environmental basic public service

5.1Financial instruments for environmental protection

Many public financial policies have been adopted at present in environmental protection areas in China, with the operation analysis as follows：

（1）Budget policy——most powerful and influential financial instrument. Currently the budget item for environmental protection is developed. However, the actual fund investment is not guranteed even the account is etablished. The related research report by Chinese Acaemy for Environmental Sciences has shown that the phenomenom of “having the channel yet without water” exists with environmental budget item. The total amount invested on environmental protection is also exagerated due to the inconsistent statistices. According to international experiences, the environmental investment should be ensured at 1.5% of GDP or above in order to change the worsening situation of environmental quality in China. With the current available national strengthen, it is necessary to set a hard target for the ratio of envirnmental protection fund in the total financial expenditure. The growth rate should be higher than that of GDP to meet the demand for the environmental protection with rapid economic growth.

（2）Tax policy——The environmetal tax reform is being undertaken.To raise the prices for resources and make it more close to its actual value, is the most effective way and also the biggest socail risk.。For example, many cities are gradually increasing the prices for water and sewage treatment, and “tiered water price”was also suggested.. Meanwhile subsidies have been provided in the less developed regions, or to the lowest income groups, in order to guarantee the basic living conditions of the vulnerable groups;

Incentive tax policy includes: those enterprises purchasing environment equipments can enjoy preferential policy, such as value added tax offset, pretax loan payment etc.

（3）Subsidies---The studies show that the direct subsidies to the consumers are most effective, and the standards applied are more fair when counting the household as a whole instead of accounting as individual. However, Chinese government tends to provide subsidies to manufacters due to the difficulties in counting and management, for example, subsidies for the minimum treatment at sewage plants, electricity price for desulphrization etc.

（3）Depreciation policy ----The policy of speeding up the depreciation of environment equipments can be adopted at those enterprises installing pollution treatment equipments, to reduce the treatment costs of the enterprises. Besides this, the same policy can be applied for those using pollution free and less polluting environmental equipments, to promote the upgrade of the enterprises. Many technical issues should be addressed, such as the identification scope and standards for environmental equipments.

（4）Government purchasing--- therotically it is promoting the acceleration of environmental industry in China, especially when the industry is in its infancy, the technical and self research level can not compete with foreign countries. This is when the government purchasing policy can play an important role. But in reality, the policy support for the domestic environmental industry may not last long and the result is hard to predict due to the increasing pressure of GPA negotiations. However, the government purchasing is effective to meet the target of improving the environment qualities in China.

（5）Ecological compensation --- The ecological compenstaion policy is implemented at pilot sites, in order to balance the interest relations between the water usage regions and water conservation regions. Shanghai is working on the formulation of the related system for the ecological compensation. Currently the fund source mainly depends on the financial policy transfer, ppp expansion principle---"users pay""affected group being compensated", the future ecological compensation fund for the inhabitants of water sources should also come from consumers.

（6）Joint venture of public and private sectors, social financing for ppp---This policy is the common practice in those countries with well developed market economic systems.Some cities in China have gained certain experiences in market operations at sewage treatment plants. According to the statistics data from water network, there are 1408 sewage treatment plants established and operated in the country by the end of May, 2008. Among these, 448 sewage plants were established and operated with BOT, TOT model, accounting for 31.8% among the operated sewage treatment plants. (369 BOT projects and 79 TOT projects); Among the 1004 sewage treatment plants calculated by Ministry of Construction, 353 projects with BOT and TOT model(5 were TOT), accounting for 34.66% of the projects being built. [5]。

[5] 中国水网 China Water Network:http://www2.h2o-china.com/report/2009/2009botreport

5.2 Financial policies assembly for environmental basic public services

Based on this research scope, the environmental basic public services should at least cover the following aspects, which can be classified into two categories: pollutants cleaning and pollutants regulation, to be more specific, the services to provide:① channels for obtaining safe drinking water；② sewage treatment;③ wastes cleaning, transfer and safe treatment；④waste gas and particulates cleaning;⑤noise control；⑥monitoring and regulation；⑦emergent incidence response；⑧information；⑨ restoration of the remaining "brown soil" etc.

Currently, the water supply in urban and rural areas can basically satisfy the demand, although the water resource per capita is inadequate and water usage is a pressing issue in many regions; The central sewage treatment facilities have been basically completed. What is lacking is the pipeline construction and operation maintenance and management; The bottleneck at the solid wastes treatment and disposal is the poor classification and over landfilled sites; The regulations over the environmental quality of water, air and noise in public areas and other environmental issues are within the work scope of environmental sectors; The contaminated sites are still be discussed. The overall management level witnesses a big gap between China and developed countries, but it is gradually improving, which is not the most urgent task at present. However, we still have 252 million rural population taking unsafe drinking water, with only 35.6% of their water meeting the quality standards (2007 data[6]）, and many other services are not available for them.

The environmental basic public service in many rural areas are at very low level.The "dual" economic structures existed many years resulted in the lower average income, living standards and consumption levels of the farmers compared to those living in cities and counties. The more allocation of financial fund to urban and county regions further widened the gap beteween rural areas and urban & country regions in their infrastructure level.

The above-mentioned services for rural areas should be directly invested by the government at this stage, and the residents should be able to use thsee services freely (or at low costs) for a certain period of time, they should develop the new living and consuming habits. For example, the fee collection model for public transportation in Beijing can be used as reference---2 Yuan/trip dropped to 0.4Yuan/trip for common

6 Website for Ministry of Water Resources
http://www.mwr.gov.cn/slzx/mtzs/zyrmgbdstzgw/200802/t20080204_111177.html

residents, 0.2Yuan/trip for students, and free for elderly, the loss for the public transportation system is subisidized by financial revenues.

Considering the current financial weakness of rural areas for its tasks, and the low social financing, thus the central and provincial transfer of fund to rural areas are the only financial sources.

See 5-1 for detailed policy instruments to meet the above-mentioned public services

Table 5-1 Matrix for environmental basic public services and financial policy instruments

Policy instruments		Drinking water	Sewage treatment	Wastes treatment	Waste gas cleaning	Noise control	Monitoring and regulation	Emergent incidence response	Information service	Contaminated soil restoration
Government investment	Transfer payment	●	●	●	●	●	●	●	●	●
	Special fund	●	●	●	●	●	●	●	●	●
	National bond	●	●	●	●	●	●	●		●
	Policy loan	●	●	●	●	●				○
Government purchasing		●	●	●	●		●			○
Operation subsidies		●	●	●	●					○
Preferential tax for operating enterprises		●	●	●	●	●				○
Joint venture of public and private sectors		○	●	●	○	○	○	○	○	○

Ecological compensation	●								○

Note：●main instruments for near term-mid term；○achievable instruments for mid - long term

*Ecological compensation is an economic instrument, which fund mainly comes from the financial transfer payment, therefore it is listed here.

5.3 Policy recommendations

The experiences gained through the practical application of financial instrument in analyzing the Chinese financial policies will be useful to the environmental basic public services:

(1) The government should increase the investment on environmental basic services

Among the "three horses" driving the GDP growth in the last ten years or more, the contribution of investment remained at level of 20-30% in the most time period of 80s and 90s. It increased rapidly up to 50% or more since we entered the 21th century, with peak value of 63.7% in 2003; The contribution of exporting to GDP fluctuaged, remained unstable. It was the key growth point from 2005 to 2007, contributing around 20%, however，it had both positive and negative contributions；While the contribution of consumption reached as high as 90% or more in the last century, but dropped below 40% this century. [7]。Recalling the rules for the economic operation, the government invested more on roads and other economic foundations, but less on the social insurance and people's livelihood. The public still are conservative for the future medical, retirement and other social insurance, especially in the rural areas, the traditional land reliance and family forms are gradually shrinking， the new social insurance system is not established yet. Therefore, it is hard to achieve the goals of expanding social financing, attracting more private fund into the economic operation, increasing consumption level, and upgrading consumption structure etc. Thus the government investment was necessary to expand the domestic demand which is still inadequate, when facing the second financial crisis.

The rationale for govenment's increasing investment on the environmental basic public services are as follows:

①The environmental infrastructure is not only the biggest project involving

[7] Source: 《中国统计年鉴 2009》

people’s livelihood, but also the growth point for future consumption. The consumption will increase with the increasing living standard and desire for better environment in our development process of moving towards moderately well developed society。

②Government financial suppor t is urgent as the environmental basic services is in its infancy with poor profits.

We had bad experiences with social financing expansion in the past, when the government invested too much on the profitable projects, causing the “squeezing out” of the private funds. The environmental basic public services are being studied and will be gradually popularized, with low profit, and inadequate capacity for commercial loan payment and social financing. It is the time requiring the government support.

(2)Focusing from the project establishment, to increase the fund application efficiency of the govenment

The waste of government fund during its application should be avoided as much as possible even though it is controlled by planning, auditting, budgeting and other sectors. Many problems occurred due to the differrent management and planning at local environmental administrations, inadequate management experiences and other reasons，such as the inappropriate project scale，incorrect technology selection for the local conditions, unsmooth allocation of local matching fund, insufficient mobile fund transfer, and delayed project initiation etc., causing the low efficiency of the government fund.

For the rural areas, taking sewage treatment plant as an example, it is most economic and efficient to use decentralized treatment method, making use of the local conditions and characteristics. However, this type of projects are often left behind because the applying units are often not aware of the application time, or these projects are rejected because their application forms and budgets may not meet the required standards. While those matured technology from home and abroad, large and midium sized projects are more likely to be credited and approved. However, in practice, we have many bad examples due to the imcompatibility of foreighn technology and devices with our climate, or the 30% of the operation load as the result of large scale design of the projects, which not only wasted so much of the fund, but also affected government’s credit. Other supporting projects for agricultural technology should be used as reference in the new round of environmental investment, especially when supporting the rural areas. Besides assisting many small projects with applying， education, training and promotion should be strengthened for the rural areas. The fund should be allowed to be listed in the budget for the project.

(3) Matching research should be first conducted

As mentioned above at 5.1，many bottlenecks encountered during the implementaion of the financial instruments need breakthrough, and the management model, economic level, social demand and other factors had great impact on the policy effects. The related system should be established and research for the technical standards conducted first in order to guarantee the effectiveness of the financial instruments implementation, which include:subjects integration for financial budget, preferential taxation for enterprises, speeding up the scope identification and standards setting for depreciated environmental devices, targets for compensation and subsidies, standards and rules for different means etc.

6 Conclusion and discussion

6.1 Exploration on the scope for environmental basic services

The identification of the content and scope for environmental basic services is the basis for the research. However, there exists big dispute over the content and scope for environmental basic services. Some suggest wider scope, some prefer limited scope. The research for the environmental basic services is quite new, therefore, although the context provided preliminary identification of the scope for the environmental basic services, more related research work is needed. The concept of environmental basic services will be accurately defined in the next phase combining the international experiences with the domestic practices. The scope will be determined based on the public survey, experts consultation and government coordination considering its basicness, universality, urgentness and feasibility.

6.2 Responsibilities division for the environmental basic public services

The clear division of the responsibilities is prerequisite for achieving the fairness of the basic public services. However, the current environmental responsibilities division in China is unclear, “financial rights at upper level, working responsibilities at lower level” caused the disconnection between the financial rights and environmental responsibilites, thus severely affected the improvement of the environmental basic public service.. Therefore, further study should be conducted next to identify the rights and responsibilities of central government and local authorities at differetn levels. The principle of “responsibilities determine the financial rights” should be followed to promote the reform in financial tax system.

6.3 Priorities for the development of the environmental basic public services

The current status of environmental services in China is that there is a big gap between urban and rural areas, among different regions, meanwhile the non-point source pollution in rural areas accounted for 50% or more of the total discharge volume, which is hard to control. Therefore, the priority development is at the rural areas, especially those poor regions. The central fund is the main sources at this stage due to the limited local financial sources, with special fund transfer as the means of payment, and market financing capacity will be gradually developed after years of operation.

6.4 Prospect for marketized operation

The future socialized and marketized operation for the environmental basic public service is the trend although the financial fund is the main sources at present. It is our current task to attract social investment with financial fund, reduce the risks of the enterprises with government investment, establish sound management mechanisms, cultivate the market, support the industrial development, and create the space for the profit generated from environmental services.

Reference

[1] SU Ming, FU Zhihua. Research on Fiscal and Tax Policies for Energy Conservation and Emission Reduction. China Financial & Economic Publishing House.2008.

[2] Center for Public Policy Studies of Shanghai University of Finance and Economics. China's Financial Development Report. 2008. Shanghai University of Financial & Economics Press CO.LTD. 2008.

[3] Center for Public Policy Studies of Shanghai University of Finance and Economics. China's Financial Development Report. 2009. Shanghai University of Financial & Economics Press CO.LTD. 2009.

Potential Welfare Loss from Using Imperfect Environmental Taxes

Inkee Hong*

Economics Department
Daegu University

Last revised on July 9, 2010

[Abstract]

In environmental policy areas, a greater use of ‘economic instruments’ (EIs) in environmental policy area has recently been observed in many countries. However, EIs are heterogeneous policy tools. The textbook case of a Pigouvian tax is far from widely used, mainly due to the information requirements and other structural and institutional constraints. The successful implementation of EIs might heavily depend on pre-existing structural and institutional conditions. Moreover, these institutional conditions are particularly unfavorable in developing countries. Using a simple analytical general equilibrium model, this paper examines how these constraints affect the welfare gain from the introduction of environmental taxes in developing countries. First, this paper solves for the second-best optimal Pigouvian tax and output tax in the presence of a distortionary tax on market use of labor. The result confirms that an environmental output tax achieves a socially-efficient level of emissions in the least-cost manner *only if* the nature of the linkage between the tax base and the environmental damage is fixed. Second, incorporating structural and institutional constraints into the model through a set of parameter values from China and the US, this paper calculates the net welfare effects of either using the ideal Pigouvian tax instead using an output tax. The numerical simulation results show that the net welfare gain from the use of an ideal Pigouvian tax could be more than *four* times larger than that of an output tax in developing countries. On the other hand, the welfare gain is only 50 percent in developed countries. This means that the potential welfare disadvantage from using output taxes instead emissions tax for environmental purposes could be much greater in the case of developing countries.

JEL Codes: H21; H23; Q56;
Keywords: Emissions Tax; Output Tax; Developing Countries

---

* I would like to thank to Don Fullerton, Pete Wilcoxen, David Eaton for many insightful comments for the earlier versions of this paper. I welcome any comments and suggestions. All errors remain my own. Contact Info: Economics Department, Daegu University, Jillyang, Gyeongsan, Gyeongbuk 712-714, Republic of Korea (Tel: 82-53-850-6211, Fax: 82-53-850-6279; e-mail: ihong@daegu.ac.kr).

I. Introduction

Many developed countries have implemented various policy measures to protect and improve the quality of their environment. Recent studies (OECD, 1995; 1996) have identified major advantages to a greater use of 'economic instruments' (EIs) such as taxes or charges and tradable permits in environmental policy, compared to 'command and control' (CAC) approaches. However, EIs are heterogeneous policy tools. The textbook case of a Pigouvian tax is far from widely used, mainly due to the information requirements and other institutional constraints (McMorran and Nellor, 1994). The successful implementation of EIs might heavily depend on pre-existing institutional conditions (see, for example, Russell and Powell, 1996; Smith, 1997).

These institutional conditions are particularly unfavorable in developing countries. Existing regulations, usually fashioned after those in developed countries, have often proven unenforceable and impractical. The efforts required to cope with the design of these policies and institutional changes for launching EIs are additional burdens on those developing nations (Panayotou, 1991; Serôa da Motta, et al 1999). Developing countries also have other structural characteristics different from those of developed countries. They often use more polluting fuels such as coal and unleaded gasoline, engage in more-harmful and less-efficient consumption and production activities such as slash-and-burn farming in Brazil, and drive more polluting vehicles per mile traveled such as small scooters in many South Asian countries. Finally, they tend to have agricultural that are large and often under-taxed, polluting industries that account for a large proportion of total output, and high marginal environmental damages per unit of output.

This paper examines how these constraints affect the welfare gain from the introduction of environmental taxes in developing countries. It uses a simple analytical general equilibrium model with three sectors: one taxable clean manufacturing sector, one polluting manufacturing sector, and one non-taxable clean sector that represents subsistence farming and/or small non-market production activities.

First, this paper theoretically shows that an ideal Pigouvian tax provides larger welfare gain than an output tax. Leaving aside problems of monitoring or enforcement, a Pigouvian tax is an ideal instrument to internalize an environmental externality because it reduces consumption of the output as well as use of the dirty input. Since emissions themselves are often hard to measure, however, both developed and developing countries have often relied on the taxation of output of the polluting industry. Using the log-linearization technique, this paper solves for the second-best optimal Pigouvian tax and output tax in the presence of a distortionary tax on market use of labor (or equivalently, a pre-existing consumption tax on all market goods).

Second, the model allows structural constraints to be incorporated and quantified through a set of parameter values rather than relies on anecdotal evidence that developing countries have experienced. The paper uses data for China, which is believed to share many characteristics commonly observed in developing countries in a broad sense. Using the data for China, I calculate the net welfare effects of either using the ideal Pigouvian tax instead using an output tax. The numerical simulation results show that the net welfare gain from the use of a Pigouvian tax could be more than *four* times larger than that of an output tax. On the other hand, the welfare gain from using a Pigouvian tax is only 50 percent larger than that of an output tax in developed countries. Therefore, the potential welfare disadvantage from using output taxes for environmental purposes appears to be greater in developing countries. This potential welfare disadvantage implies that developing countries' efforts in various structural reforms have important effects on the welfare outcomes of their environmental policies. Moreover, the welfare disadvantage does not imply that developing countries should avoid using environmental output tax instruments. Although an introduction of an environmental output tax offers smaller welfare gain in developing countries than in developed countries, the welfare gain from output tax instruments might be substantial, considering the potential savings from monitoring and enforcement activities.

Section II briefly overviews past experiences with EIs as well as the previous literature. In Section III, I present the model and derive the optimal tax rates and net welfare expressions for both the emissions tax and output tax. Section IV discusses the implications of these analytical results, while Section V presents simulation results. Section VI concludes.

II. Past Experiences with Economic Instruments

The traditional and most direct approach to environmental management is to impose technology restrictions and guidelines, enforced using fines and fees. But this CAC method can be difficult and expensive to implement, monitor, and enforce. In the economic literature, the CAC approach has been deplored on grounds of both static and dynamic inefficiency, because it asks for the same level of compliance by all polluters despite differences in marginal abatement costs. Furthermore, it does not provide any incentives to polluters for technical improvement to reduce pollution in the future (Baumol and Oates, 1988; Cropper and Oates, 1992).

EIs include both taxes and permit systems, but the model in this paper is based on perfect certainty and thus does not really distinguish between them. Since taxes and permits are equivalent, I refer only to Pigouvian taxes (fees or charges) and environmental output taxes.[1] A Pigouvian tax (or emissions tax) is a specific tax per unit of emissions. The optimal rate of tax is equal to the pollutant's social marginal environmental damage (MED) at the socially-efficient level of emissions (Pigou, 1932). In theory, Pigouvian taxes reduce pollution in the least-cost manner: they encourage

[1] Some studies (OECD, 1999b; Smith, 1997) divide environmental tax instruments into charges (or fees) and taxes based on whether they are requited or not. However, in this paper, I will use all these terms interchangeably.

polluters to determine the combination of lower output, substitution among inputs, and investment in new technology that reduces emissions at least cost.

On the other hand, taxes on output or purchased inputs might be used for environmental purposes, though they have traditionally been used mainly for revenue purposes.[2] In many cases, they are intended to encourage pollution abatement by taxing outputs or inputs whose use is *linked* to environmental damage, rather than taxing emissions directly. Unlike a Pigouvian tax, however, an output (or input) tax achieves a socially-efficient level of emissions in the least-cost manner *only if* the nature of the linkage between the tax base and the environmental damage is fixed. Without fixed linkage to pollution, they usually deliver only the output effect (Fullerton, et al, 2001). In other words, they do not provide incentives to abate emissions per unit of output; they only reduce consumption of goods and services produced using emissions.[3] Furthermore, they may affect other non-targeted activities (Eskeland and Jimenez, 1992).

Why are environmental output (or input) taxes so popular then? First of all, environmental output taxes are relatively easier to administer than ideal Pigouvian taxes. For design and implementation of a perfect Pigouvian tax, the environmental authorities would have to monitor the sources of pollutants continuously, enforce the potential polluters to comply, and decide the optimal rate of tax for each polluter. These administrative activities are by no means easy tasks, even in developed countries.[4] The situations in many developing countries are worse: their institutional weaknesses such

---

[2] I will use "Pigouvian tax" for a tax per unit of emissions and "output tax" for a tax on output of the polluting industry. Therefore, by my definition, the most important characteristic in determining if any particular tax (or charge) belongs to the Pigouvian tax category depends on whether it directly hits the emissions themselves. If not, I will call it an output tax.

[3] For instance, a tax on coal intended to reduce sulfur emissions will also affect manufacturers that use coal to extract chemicals for dyeing. If a tax were imposed on the sulfur content of coal, the manufacturers in the dyeing industry would unnecessarily be induced to switch to lower-sulfur coal or to find other sources of chemicals (Blackman and Harrington, 2000).

[4] Political considerations or the practical problems of design and implementation such as who is to be taxed are often the most important factors that determine the types of policy tools employed (Barthold, 1994).

as under-funding and inexperience tend even further to limit the effective implementation of Pigouvian taxes.[5] Furthermore, it is often difficult to introduce new environmental taxes. In comparison, output taxes are relatively easy to implement.[6] Many existing taxes are levied on the value of goods and services sold (or the value of incomes paid or received). For example, excise taxes on fuel and other energy products are probably the most widespread environmental taxes mainly because of their administrative convenience (OECD, 1999a).

A comprehensive survey of the use of EIs (OECD, 1989) reports over 150 instances related to the purpose of environmental improvement in 14 OECD countries. However, many taxes and charges adopted partly for environmental reasons were mainly for the purpose of raising revenues. Other surveys show a rising trend in the use of EIs in developed countries. OECD (1994) reports the number of EIs increased almost 50 percent just from 1987 to 1991. Covering the years 1997-1999, OECD (1999b) shows that all of the OECD Member countries that responded to the questionnaire (24 out of 29) are using some types of EIs.

However, the popularity of EIs among developed countries often blurs the true nature of environmental instruments: many environmental taxes titled "emission charges or fees" usually are *not* exactly Pigouvian taxes. As Fullerton, et al (2001) emphasize, most charges on various pollutants are not Pigouvian taxes, no matter what they are called. Difficulties in precisely monitoring the levels of pollutants force many developed countries to use less-ambitious charges or taxes on the bases that are easier to observe and enforce (OECD, 1999a).

---

[5] This does not necessarily imply that environmental output taxes are free from such institutional constraints, only that such constraints may be smaller for an output tax.

[6] Smith (1996) points out that "where the assessment, collection, or enforcement of the tax can be 'piggy-backed' on to corresponding operations already established for existing taxes, the costs of an environmental tax measure may be significantly lower than where entirely-new administrative apparatus and procedures are required."

The situations in developing countries are not much different and might be worse.[7] Technological constraints such as the use of dated technologies are mixed with structural constraints such as large numbers of small polluters that are hard to regulate, large traditional sectors, high bureaucratic cost, corruption, lack of political will, and severe shortage of budget and manpower. All these factors make it more difficult to implement EIs successfully. In China, for example, emission fees are charged on 20 different air pollutants. However, firms are required to pay fees only for the 'worst case pollutant,' even when more than one pollutant exceeds the permissible level. Other pollutants face *no* charge at the margin.[8] Worsening these problems is that fees reduce firms' tax liabilities, and that 80 percent of fees are eventually returned to these firms. These problems cause perverse incentives for firms to perpetuate noncompliance (Blackman and Harrington, 2000).[9]

Though the literature on environmental taxes is vast, it usually assumes that emissions can be perfectly observable, or that a tax on the consumption good or a tax on a market input corresponds exactly to a tax on emissions. An early example is Sandmo (1975). He examines the optimal tax rate when the aggregate amount of one of the consumption goods enters the utility function directly as a negative externality. Thus, he assumes that the relation between the output and the externality is fixed, where only

[7] In addition to the difficulties with monitoring and enforcement of effective environmental policy instruments, many developing countries have distinct structural characteristics different from developed countries. They are often characterized by a large share of agriculture in total output and employment, and by large share of informal (or non-taxable) economic activities (Tanzi and Zee, 2000). Due to these constraints, many developing countries have relied heavily on indirect consumption taxes such as sales or excise taxes. This paper takes advantage of the fact that a uniform consumption tax on market output is equivalent to a uniform tax on market labor.

[8] Furthermore, actual monitoring of emissions is based only on visual inspection of the clarity of flue gases. Actual fees are determined in combination with estimates of emissions volumes, but many studies point out that the emissions fees are well below marginal abatement costs for most firms and thus provide limited abatement incentives (Yang, et al, 1997).

[9] In order to solve administrative difficulties in implementing an emissions tax, developing countries often rely on other policy instruments: product taxes on fuels in many countries, voluntary agreements and information disclosure such as the Clean River Program in Indonesia (O'Connor, 1998). However, the overall evaluation of experiences with EIs in many developing countries indicates that EIs have potentially increased technical and financial burdens on already-fragile institutional structures (Serôa da Motta, et al, 1999; McMorran and Nellor, 1994).

changes in output level can reduce the emissions level. In this case, a tax on emissions is equivalent to a tax on the output of the polluting industry.

Cremer and Gahvari (2001) re-examine the results of Sandmo in the case where taxation of a consumption good is not equivalent to a tax on emissions. In a second-best world with distorting labor taxes, they show that taxes on emissions and on consumption goods can be set separately to address different objectives: an emission tax solves the externality problem while output taxes are determined in conformity with optimal tax considerations. However, they do not examine the magnitude of possible welfare losses from using an output tax instead of an emissions tax, since they still assume that a firm’s emission level is fully observable.

Cropper and Oates (1992) have suggested that output taxes may be superior to an emissions tax if monitoring is costly. Schmutzler and Goulder (1997) explicitly examine the importance of monitoring costs in the choice between taxes on emissions and taxes on outputs (or inputs). Under imperfect monitoring, they show that output taxes might be preferred to emissions taxes if outputs are easily substitutable and abatement options are scarce. Hoel (1998) also argues that emission taxes may be no more effective than other policies if abatement costs are uncertain and non-convex, and if measuring emissions is difficult.

Vatn (1998) approaches the problem in a different way. Using a material balance perspective in his model, he assumes that all economic activities such as extraction, production, and consumption generate emissions. Normally, it becomes harder and more expensive to detect and mitigate them in the later stages of economic activities, since emissions become part of numerous inputs and outputs. If transaction costs internalizing the externalities outweigh the gains from hitting the target more precisely by using an emissions tax, the use of input-oriented taxes might be more efficient.[10]

---

[10] Broadly speaking, transaction costs include monitoring, enforcement, and other controlling costs incurred by the environmental authorities.

To compare alternative taxes, Fullerton, et al (2001) start by showing theoretically and numerically that the emissions tax raises welfare more than an output tax. They do not explicitly measure or model the costs of targeting the tax on pollution, such as the costs of measurement, monitoring, and enforcement, but their numerical simulation results show how big those costs must be to justify the use of the output tax instead. In a more direct comparison, Smulders and Vollebergh (2001) explore the trade-off between incentive effects and administrative costs associated with the implementation of various environmental tax instruments. They find that the output tax might be favored if emissions are closely linked to the uses of output, if other technological abatement methods are not plentiful, and if administrative costs of the emissions tax are high. Others argue that output or input taxes such as fuel taxes can be quite effective to control air pollution in developing countries if accompanied by emissions standards to stimulate cleaner technologies (Eskeland, 1995; Eskeland, et al, 1998).

III. The Model

The developing country model has three production sectors: two taxable manufacturing sectors $(X \text{ and } Y)$ and one non-taxable subsistence agricultural sector (Z). This static model considers only one time period, with no saving decision. The N identical households obtain utility from the clean manufactured good (X), the dirty good (Y), the clean agricultural good (Z), a government-produced public good (G), and environmental quality (E).

The household allocates a fixed amount of time $(\bar{L})$ between taxable labor (L) and non-taxable labor (L_Z). For simplicity, I refer to the resource as time available for labor supply, but more generally, it can be a fixed total amount of all resources such as labor, capital, land, and energy. In that case, L can be interpreted as the resources used in the market, where L_Z is the amount used for subsistence agriculture. This reflects not only the conceptual problems in measuring agricultural income for taxation, but also administrative difficulties in monitoring and enforcement of that tax.[11] Therefore, I assume that Z is non-taxable.[12]

The clean good is produced with a constant returns to scale production technology using only labor (L_X), while a dirty good is produced with a constant returns to scale production technology using labor (L_Y) and emissions (D):

$$X = L_X \tag{1}$$

and
$$Y = F(L_Y,\ D) \tag{2}$$

For convenience, a unit of X is defined as the amount that can be produced using one unit of labor. The numeraire is labor (or equivalently, X).

The agricultural sector produces a non-taxable clean good (Z) with constant returns to scale technology using only labor as an input:

$$Z = L_Z, \tag{3}$$

where a unit of Z is defined as the amount that can be produced using one unit of labor.

Both manufacturing outputs are assumed to be taxable. For environmental reasons, the output of the polluting sector (Y) might be taxed at a rate higher than that of the non-polluting sector (X). This paper will focus on the differential, that is, the *extra* tax on the output of the dirty industry. In addition, note that any uniform tax on

---

[11] The governments in many developing countries often have difficulties in finding suitable tax tools, especially when the transaction arises within the household or between households using informal markets. In this sense, a non-taxable clean agricultural good (*Z*) might be interpreted instead as all informal economic activities. See Schneider and Enste (2000) for an empirical assessment of the size of the underground economy for developing countries as well as OECD countries.

[12] It is well known that many countries exempt consumption taxes on foods and other agricultural products for the purpose of income distribution.

outputs X and Y is equivalent to a tax on labor used in those two sectors, since labor is the only source of income in this model. For these reasons, this model will use a tax on labor (t_L) to represent the uniform or common portion of the output taxes on X and Y. Then, the output tax on a dirty consumption good (t_Y) is the extra tax on output of the dirty industry.

Emissions (D) are a dirty input that can be disposal of gaseous, liquid, and solid waste used to produce output. Note that the production function for Y has variable pollution, D per unit of output. This disposal is assumed to inflict some *private* cost on producers in terms of resources (labor), and a unit of emissions can be defined as the amount that requires one unit of resources:

$$D = L_D \,. \tag{4}$$

Thus, the firm has constant private marginal cost of pollution, equal to one, so it chooses a finite amount of pollution. Because of the negative externality, however, the firm's choice is not socially optimal. Aggregate emissions (ND) have a harmful effect on overall environmental quality (E):

$$E = e(ND), \tag{5}$$

where $e' \equiv \partial e / \partial D < 0$. The model also assumes perfect competition, certainty, complete information, and perfect factor mobility between sectors.

Government produces a public good using labor:

$$G = NL_G \,. \tag{6}$$

Government finances the public good with the tax on market labor (t_L) and the output tax on a dirty consumption good (t_Y), and possibly a tax on emissions (t_D). Hence, the government budget constraint is

$$G = N(t_L L + t_Y Y + t_D D). \quad (7)$$

For convenience, the consumer price for the polluting manufactured good (c_Y) is defined as the sum of the producer price (p_Y) and the output tax (t_Y). The nominal wage is normalized to one, and $p_X = p_Z = 1$ as well. Without loss of generality, assume that the initial producer price of Y is normalized to one (i.e., $p_Y = 1$).

Finally, the economy's overall resource constraint is given by

$$NL = NX + N(L_Y + D) + G. \quad (8)$$

A representative household maximizes the utility function, $U = U(X,\ Y,\ Z;\ G,\ E)$, subject to the budget constraint, $(1 - t_L)L = X + (1 + t_Y)Y$. Taxable labor supply is given by $L = L_X + L_Y + L_D + L_G$. From the first-order conditions, we have $U_X = U_Y/(1 + t_Y) = U_Z/(1 - t_L) = \lambda$, where a subscript on U denotes a marginal utility from that good (U_Z is the partial derivative of U with respect to L_Z), and λ is the private marginal utility of income.[13]

Using log-linearization techniques, appropriate for small changes, I derive equations that show the impacts of a tax change on prices, quantities, and welfare.

In general, I start at an initial competitive equilibrium with possible pre-existing t_L, t_Y, and t_D. Special cases are considered where one or more of those taxes are not possible (i.e., are set to zero). The model then can be used to show all of the effects of a small increase in the emissions tax or if that is not possible, then a small increase in the output tax. In all cases, the revenue is returned through a reduction in the pre-existing tax on market labor so that G is not affected $(dG = 0)$. The effect of any such

[13] In the representative household's utility maximization, it is assumed that she considers the environmental quality (E) and the public good (G) to be independent of her own choices. This assumption is appropriate if the number of consumers (N) is large.

change on utility can be expressed by totally differentiating the household's utility function:

$$dU = U_X dX + U_Y dY - U_Z dL + U_E N e' dD. \tag{9}$$

Totally differentiate the overall resource constraint (8), divide it by N, and set $dG = 0$, to get:

$$dX = dL - dL_Y - dD. \tag{10}$$

Next, plug the first-order conditions from the utility maximization and (10) into (9), and divide it by the Lagrange multiplier (λ), to get:

$$dU/\lambda = dX + (1 + t_Y) dY - (1 - t_L) dL - \mu dD, \tag{11}$$

where dU is the change in a representative household's utility. The term μ equals $-NU_E e'/\lambda$ and denotes the MED from emissions.

Totally differentiate the production function of the dirty good (2):

$$dY = F_{L_Y} dL_Y + F_D dD, \tag{12}$$

where $F_i \equiv \partial F(\bullet)/\partial i$ for $i = L_Y$ and D. Then, substitute the first-order conditions from the profit maximization into (12) to get:[14]

$$dY = dL_Y + (1 + t_D) dD. \tag{13}$$

Finally, plug (13) into (11) and divide the both sides of the equation by L, then

---

[14] Maximizing the profit function, $\Pi = F(L_Y,\ D) - L_Y - (1 + t_D) D$, gives the first-order conditions: $F_{L_Y} = 1$ and $F_D = (1 + t_D)$.

$$\frac{dU}{\lambda L} = t_L \hat{L} + t_Y \left(\frac{Y}{L}\right) \hat{Y} + (t_D - \mu)\left(\frac{D}{L}\right) \hat{D}, \tag{14}$$

where a hat over a variable denotes a percentage change (e.g., $\hat{L} = dL/L$). The left hand side of this expression is the change in welfare in terms of a particular monetary unit $\left(dU/\lambda\right)$ as a fraction of the total return to market labor in the economy (L). The right hand side consists of three parts. The first and second parts are the welfare effects of the environmental policy through its impact on the amount of the market labor $(\hat{L})$ and the dirty manufactured good $(\hat{Y})$. The third term is the welfare impact resulting from the change in pollution $(\hat{D})$. Note that if either a tax on the market labor (t_L) or the extra consumption tax on the dirty good (t_Y) is set to zero, then the corresponding welfare effect disappears from the equation. Also note that, even without any pre-existing taxes $(t_L = t_Y = 0)$ in theory, the developing country can successfully internalize the externality by imposing a Pigouvian tax on emissions (t_D) equal to the MED (μ). The rate $t_D = \mu$ then maximizes utility $(dU = 0)$.

Next, totally differentiate the government budget constraint (7), divide it by the total amount of labor supply in the manufacturing sectors (NL), hold G fixed $(dG = 0)$, and divide it again by $(1 - t_L)$ to get:

$$\hat{t}_L = -\frac{t_L}{(1-t_L)}\hat{L} - \frac{(1+t_Y)Y}{(1-t_L)L}\left[\hat{t}_Y + \frac{t_Y}{(1+t_Y)}\hat{Y}\right] - \frac{(1+t_D)D}{(1-t_L)L}\left[\hat{t}_D + \frac{t_D}{(1+t_D)}\hat{D}\right], \tag{15}$$

where $\hat{t}_L \equiv dt_L/(1-t_L)$, $\hat{t}_D \equiv dt_D/(1+t_D)$, and $\hat{t}_Y \equiv dt_Y/(1+t_Y)$. This is the change in t_L necessary for government to balance the budget when changing t_Y or t_D. To evaluate this expression, the next step is to solve for $\hat{L}$, $\hat{Y}$, and $\hat{D}$ in terms of two environmental tax instruments: $\hat{t}_Y$ and $\hat{t}_D$.

In order to find analytical solutions to (14) and (15), one needs to make some assumptions on consumer preferences. In particular, assume that environmental quality (E) and the public good (G) are separable from the consumption goods

$(X,\ Y,\ \text{and}\ Z)$ and that the consumption goods enter utility in a homothetic sub-utility function as in Bovenberg and de Mooij (1994) or Fullerton and Metcalf (2001):

$$U(X,\ Y,\ Z;\ G,\ E) = U\Big(V\big(Q(X,\ Y),\ Z\big),\ G,\ E\Big), \tag{16}$$

where $V(\bullet)$ and $Q(\bullet)$ are both homothetic. For later use, define p_Q as a price index on $Q(X,\ Y)$ such that

$$p_Q Q = p_X X + c_Y Y \tag{17}$$

and let w be the real net wage, $w = (1 - t_L)/p_Q$.

Totally differentiate (17) and divide it by p_Q to get:

$$\hat{p}_Q = \frac{Y}{(1 - t_L)L}\hat{p}_Y + \frac{(1 + t_Y)Y}{(1 - t_L)L}\hat{t}_Y\,. \tag{18}$$

Since $p_X = 1$ always, the change in the overall price index $(\hat{p}_Q)$ depends on the change in the producer price of a dirty good $(\hat{p}_Y)$ and the change in its output tax $(\hat{t}_Y)$.

For the change in the producer price of a dirty output $(\hat{p}_Y)$, Appendix A shows how to use the zero-profit condition and the first-order conditions from profit maximization to obtain:

$$\hat{p}_Y = \frac{(1 + t_D)D}{Y}\hat{t}_D\,. \tag{19}$$

Substitute (19) into (18) to get:

$$\hat{p}_Q = \frac{(1 + t_Y)Y}{(1 - t_L)L}\hat{t}_Y + \frac{(1 + t_D)D}{(1 - t_L)L}\hat{t}_D\,. \tag{20}$$

This equation says that an increase in either t_Y or t_D results in an increase in the overall price index, and that the contribution of each depends on the expenditure shares of Y and D in after-tax labor income from the manufacturing sectors.

The definition of the real wage rate implies that $\hat{w} = -\hat{t}_L - \hat{p}_Q$. Thus:

$$\hat{w} = -\hat{t}_L - \frac{(1+t_Y)Y}{(1-t_L)L}\hat{t}_Y - \frac{(1+t_D)D}{(1-t_L)L}\hat{t}_D. \tag{21}$$

This equation says that the real net wage decreases if any tax were to increase. Again, the contribution to the change in the real net wage depends on each expenditure share. Substitute (15) into (21) to get:

$$\hat{w} = \frac{t_L}{(1-t_L)}\hat{L} + \frac{t_Y Y}{(1-t_L)L}\hat{Y} + \frac{t_D D}{(1-t_L)L}\hat{D}. \tag{22}$$

Subsistence agriculture (Z) is non-taxable and therefore operates in this model much like home production such as work in the household cooking, cleaning, child care, and gardening to grow food for the family. Therefore, the choice between market labor and home/agricultural labor acts in this model much like a labor-leisure choice in other models such as Bovenberg and de Mooij (1994) and Fullerton and Metcalf (2001). Thus, the next step is the derivation of a "labor supply" function, meaning the supply of labor to the market manufacturing sectors rather than to the non-market home/agricultural sector.

Maximization of the household's sub-utility for the composite manufactured good (Q) and a clean agricultural good $(V(Q,\ Z))$ subject to the budget constraint $(Q = wL)$ gives the function for the supply of labor to the manufacturing sectors, $L = L(w)$, and totally differentiating it yields:

$$\hat{L} = \varepsilon\hat{w}, \tag{23}$$

where ε is the uncompensated elasticity of this labor supply in the manufacturing sectors with respect to the net wage (i.e., $\varepsilon \equiv w\partial L / L\partial w$).

The equations above can be used to solve for any change as a function of the exogenous tax change, exogenous parameters, and initial values of the variables. Appendix B shows how these equations are used to solve for the key variables ($\hat{D}$, $\hat{Y}$, and $\hat{L}$).

First, the change in emissions can be expressed as follows:

$$\hat{D} = -\Theta \left\{ \begin{array}{c} \sigma_Q \left(1-\phi\right)\left[1-\left(1+\varepsilon\right)t_L\right]\hat{t}_Y \\ + \left[\begin{array}{l} \sigma_Q \left(1-\phi\right)\left[1-\left(1+\varepsilon\right)t_L\right]\dfrac{\left(1+t_D\right)D}{\left(1+t_Y\right)Y} \\ +\sigma_Y \left(\dfrac{L_Y}{Y}\right)\left[1-\left(1+\varepsilon\right)\left(t_L + t_Y \dfrac{Y}{L}\right)\right] \end{array} \right]\hat{t}_D \end{array} \right\}, \tag{24}$$

where $\phi \equiv (1+t_Y)Y / (1-t_L)L$ and $\Theta \equiv \left\{1-(1+\varepsilon)\left[t_L + t_Y\left(Y/L\right)+t_D\left(D/L\right)\right]\right\}^{-1}$.[15]

Note that the σ_Q part of $\hat{t}_D$ term is similar to the $\hat{t}_Y$ term. They represent the substitution in consumption. The σ_Y part of $\hat{t}_D$ term represents the substitution in inputs for production.

For $\hat{Y}$:

---

[15] One important assumption is that $\Theta > 0$. Since $G/NL = t_L + t_Y\left(Y/L\right)+t_D\left(D/L\right)$ from the government's budget constraint, this assumption means that the following condition needs to be satisfied: $\varepsilon < \left(NL-G\right)/G$.

$$\hat{Y} = -\Theta \left\{ \begin{array}{c} \sigma_Q \left(1-\phi\right)\left[1-\left(1+\varepsilon\right)t_L\right]\hat{t}_Y \\ + \left[\begin{array}{l} \sigma_Q \left(1-\phi\right)\left[1-\left(1+\varepsilon\right)t_L\right]\dfrac{\left(1+t_D\right)D}{\left(1+t_Y\right)Y} \\ +\sigma_Y \left(\dfrac{L_Y}{Y}\right)\left(1+\varepsilon\right)t_D\left(\dfrac{D}{L}\right) \end{array} \right]\hat{t}_D \end{array} \right\}. \tag{25}$$

Since both $\hat{D}$ and $\hat{Y}$ are used in the key welfare equation (14), these two equations ((24) and (25)) deserve further discussion. First, note that both equations have the same term for an incremental tax change of the output tax (i.e., the $\hat{t}_Y$ term). It shows that if the developing country government increases (or introduces) t_Y marginally and holds the level of the Pigouvian tax fixed (i.e., $\hat{t}_D = 0$), the effects on both the dirty input (D) and a dirty output (Y) are the same in magnitude (i.e., $\hat{Y} = \hat{D}$). Holding $\hat{t}_D = 0$ means that the government cannot (or need not) use the Pigouvian tax as an instrument for environmental improvement. This result just reflects the fact that the output tax change $\left(\hat{t}_Y\right)$ will reduce output. No change in relative input prices $\left(\hat{t}_D = 0\right)$ means that both inputs will be reduced in the same proportion ($\hat{Y} = \hat{D} = \hat{L}_Y$).

Next consider the second terms in (24) and (25) that are multiplied by $\hat{t}_D$. This *change* in relative input prices can affect D differently than Y, but only when σ_Y is not zero. With substitution in production, the firm can reduce pollution more than output $(\hat{D} \neq \hat{Y})$ and change pollution per unit of output, by an extent that increases with σ_Y. To clarify, note that if $\sigma_Y = 0$ in (24) and (25), then $\hat{t}_D$ has the exact same effect on $\hat{D}$ as an $\hat{Y}$. This corresponds to the special case where the dirty good itself generates externalities either in production or in consumption. Equivalently, suppose that pollution per unit of output is fixed. Then, the tax on a dirty output has the same effect on that output as it has on the dirty input. For example, final consumption goods such as gasoline and cigarettes may have environmental problems that come not from one of the inputs to production, but from the use of the final consumption good, so the pollution per unit of output is fixed. Therefore, $\hat{Y} = \hat{D}$, so the government can achieve the same amount of reduction in pollution either by imposing an output tax or tax on pollution. In general, however, this model *does* allow for substitution $(\sigma_Y \neq 0)$.

Finally, for $\hat{L}$:

$$\hat{L} = -\Theta\varepsilon \left\{ \begin{array}{c} \sigma_Q (1-\phi)\left[t_Y \left(\frac{Y}{L}\right) + t_D \left(\frac{D}{L}\right)\right]\hat{t}_Y \\ + \left[\sigma_Q (1-\phi)\left[t_Y \left(\frac{Y}{L}\right) + t_D \left(\frac{D}{L}\right)\right]\frac{(1+t_D)D}{(1+t_Y)Y} + \sigma_Y \left(\frac{L_Y}{Y}\right) t_D \left(\frac{D}{L}\right)\right]\hat{t}_D \end{array} \right\}. \tag{26}$$

Since $\Theta > 0$, $\varepsilon > 0$, and all of the terms inside the large brackets are positive, an increase in either t_Y or t_D *does* reduce labor use in the manufacturing sectors. This equation completes the solution for the necessary variables ($\hat{D}$, $\hat{Y}$, and $\hat{L}$) to enter the key equation (14) for the change in welfare of the economy.

If non-taxable production is clean as assumed, then environmental tax policy could generate further reductions in pollution levels through the indirect channel of reduced labor supply to taxable sectors. If instead subsistence agriculture is polluting, then environmental policy using tax instruments could cause an unwanted *increase* in the overall level of pollution. Moreover, the environmental problem could become worse, since pollution generated in the non-taxable sector cannot be regulated at all. This kind of dilemma arises when controlling inputs rather than emissions: if all inputs cannot be regulated, partial application of sub-optimal input taxes might result in unwanted substitutions among inputs and therefore might aggravate the problem.

However, it is unclear whether the sector *Z* is environmentally benign. In many developing countries, agricultural (or traditional) sectors have both characteristics: on the one hand, they usually employ environmentally-benign production technology such as less use of chemical fertilizer and tilling the soil with animals. In that case, environmental tax policy could achieve further reduction in the overall pollution level in the society by shifting labor to non-market activity. On the other hand, some developing countries like Brazil have been trying hard to reduce harmful farming activities such as slash-and-burn farming. In that case, the effect could be the opposite.[16]

IV. Environmental Tax Reforms

Suppose that the government of a developing country is considering a tax reform by raising (or introducing) t_Y with pre-existing labor tax, holding t_D fixed (i.e., $t_L > 0$, $t_D \geq 0$, $t_Y \geq 0$ and $\hat{t}_Y > 0$ but $\hat{t}_D = 0$). Then, substituting (24), (25), and (26) into (14):

$$\frac{dU}{\lambda L} = -\Theta\left[\sigma_Q (1-\phi)(1-t_L)\,\mathrm{A}\right]\hat{t}_Y\,, \tag{27}$$

where $\mathrm{A} \equiv t_Y\left(Y/L\right) + t_D\left(D/L\right) - \left\{1-\varepsilon\left[t_L/(1-t_L)\right]\right\}\mu\left(D/L\right)$.

Note that this incremental tax reform has no substitution effect between inputs. Though σ_Y is still nonzero, it is not relevant for $\hat{t}_Y$. By imposing this additional output tax, the government can reduce the consumption level of a dirty good, but it cannot induce the producers to substitute other cleaner inputs for emissions in production. Therefore, the change in t_Y has no substitution effect in production (i.e., σ_Y does not appear in (27)). Also note how the formula simplifies with no pre-existing taxes:

[16] Eskeland and Jimenez (1992) point out that small firms in the informal sector are often major polluters in developing countries. If I interpret Z as the informal sector rather than as subsistence farming, then that increases the probability of an unwanted increase in the overall pollution level.

$$\frac{dU}{\lambda L} = \sigma_Q \left(1 - \frac{Y}{L}\right) \mu \left(\frac{D}{L}\right) \hat{t}_Y , \tag{27a}$$

Welfare is always increased by a small increase in the output tax from zero if $\sigma_Q > 0$. However, as will be shown later, the magnitude of the net welfare effect from the output tax is smaller than that of the Pigouvian tax, due to the lack of a substitution effect.

Next, suppose the government raises (or introduces) t_D with the pre-existing labor tax, holding t_Y fixed (i.e., $t_L > 0$, $t_Y \geq 0$, $t_D \geq 0$, and $\hat{t}_D > 0$ but $\hat{t}_Y = 0$). Then, the welfare expression (14) simplifies:

$$\frac{dU}{\lambda L} = -\Theta \left\{ \sigma_Q (1-\phi)(1-t_L) \left[\frac{(1+t_D)D}{(1+t_Y)Y} \right] \mathrm{A} + \sigma_Y \left(\frac{L_Y}{Y} \right) \mathrm{B} \right\} \hat{t}_D , \tag{28}$$

where $\mathrm{B} \equiv t_Y \left(Y/L\right) \mu \left(D/L\right) + (1-t_L) \left\{ t_D \left(D/L\right) - \left[1 - \varepsilon\left(t_L/(1-t_L)\right)\right] \mu \left(D/L\right) \right\}$.

The first term in the large brackets represents the output effect as before (i.e., the substitution in consumption from σ_Q). The second term is the substitution effect in production from σ_Y: the producers can substitute one input for another as the relative input prices change due to $\hat{t}_D$. In other words, a small increase in the t_D raises the consumer price for Y and the consumers moves away from Y to X (and possibly to Z) due to higher price. As a result, the environmental quality improves and the welfare rises.

However, the output effect from t_D is smaller than the same effect from t_Y. Though similar to equation (27) in appearance, the first term in the large brackets (i.e., the σ_Q term) of equation (28) has an additional multiplicative term, $(1+t_D)D/(1+t_Y)Y$ in it. This is the ratio of expenditure on the dirty input to the revenue from selling the output, and it is always less than one. Thus, the output effect from t_D is always smaller than the same effect from t_Y.

The real strength of t_D, however, comes not from the output effect, but from the substitution effect. Unlike $\hat{t}_Y$ back in equation (27), the Pigouvian tax in (28) penalizes the use of D and induces the producers of Y to shift into more use of L_Y. This ability to abate emissions by input substitution is a very powerful way to improve the environment, and it thus increases the overall social welfare. As I will show later in the numerical simulation, the size of σ_Y is very important to decide the size of welfare gain. However, many developing countries appear to have much lower σ_Y than in developed countries. For example, global coal use over the next two decades is expected to rise more than 50 percent, mostly in the developing world and especially in Asia. In particular, industry accounts for two thirds of China's coal use. Industrial boilers alone consume 30 percent of China's coal. Despite the government's large investments, these highly inefficient boilers are still widely used (WRI, 1998). Hence, developing countries have difficulties in switching to more efficient and less polluting production technologies.

V. Numerical Simulation

In this section, equations (27) and (28) are used to measure the impact on welfare of a small change in either t_D or t_Y. This section employs parameter values from China, which in many respects has structural characteristics commonly found in many developing countries: a large agricultural sector, heavy dependence on indirect consumption taxes, widespread use of polluting inputs and out-dated technologies, and many geographically dispersed small point-source polluters such as Town and Village Enterprises. In the next subsection, various parameters are selected.

It is important to remember that I use the parameter values from China as an example of developing countries. I do not claim that China be considered a *prima facie* representative developing country in every possible respect. No single country can be considered to have all the institutional and structural characteristics in many developing countries over the world. I only say that China has some institutional and structural characteristics relevant to the hypothesis presented in this paper. The same reservation is explicitly made for the U.S. used here as an example of developed countries

1. Assumptions on Parameters

To measure the impact on welfare of an incremental change in either t_Y or t_D, equations (27) and (28) require values for many elasticities, shares, and initial tax rates.

For t_L, I want a tax rate that applies to the income from all household resources supplied to the market. Although the top marginal personal income tax rate in China is 45 percent, the average taxpayer faces only a 15 percent marginal tax rate (Heritage Foundation, 2000).[17] However, indirect consumption taxes such as the VAT, consumption tax, and excise taxes are usually applied to both clean and dirty manufacturing sectors in addition to the direct personal and enterprise income taxes. Currently, the VAT rate of 17 percent is applied to a large proportion of domestically-produced goods and services as well as to imported goods. However, the VAT is levied at a lower rate of 13 percent for the basic foodstuffs and agricultural goods.[18] Assuming that the VAT rate for foods and agricultural goods is the basic rate applied to every household regardless of economic activity, I safely choose 10 percent for the additional portion of tax burden from various indirect taxes. Therefore, the final rate for t_L is 0.25.

For t_Y, I need additional tax rate that applies only to the income from all market household resources engaged in polluting production activities (Y). As mentioned above, the VAT is applied differently: the 17 percent rate applies to produced goods in

---

[17] This number can be justified by another calculation. China's GDP per capita was US $3,600 in 1998, which was about 30,000 yuan (IMF, 1999a and 1999b). Applying a standard deduction of 800 yuan per month, taxable income amounts to 24,000 yuan. The tax rate for this income category is currently 15 percent (Tseng, et al, 1994).

[18] It is reduced further for goods and services provided by small-scale taxpayers (6 percent). Furthermore, the business tax is applied at 3 to 5 percent to all enterprises, institutions, or individuals providing certain types of services, assign intangible assets, or sell immovable property within China, if their turnover is greater than a threshold specified by the Ministry of Finance (Tseng, et al, 1994).

Y, the 13 percent rate applies to in X, and untaxed subsistence agriculture is part of Z. Therefore, the difference between Y and X is 4 percent. However, I will safely assume 5 percent for t_Y, because some excise taxes are levied at 3 to 8 percent on some goods such as motor vehicles (Ma, 2000).

For the uncompensated wage elasticity of market labor supply (ε), I need a single value to represent an aggregate of all workers in the manufacturing sectors and all market labor supply effects from changes in wages of the manufacturing sectors. In the case of developed countries, the literature provides many estimates of the hours elasticity that are small (or negative) for males, and other estimates that are large and positive for females. Although no specific estimates of uncompensated wage elasticities are available for China, numerous studies such as Rosenzweig (1980) and Jacoby (1993) show that the magnitudes are not much different from those in developed countries. In this model, however, ε represents elasticity of supply to the market sector rather than the non-market sector. So, I believe $\varepsilon = 0.3$ reasonable value. I also vary these numbers for sensitivity analysis later.

For Y/L, I calculate the proportion of the industries most responsible for pollution in total production. As of 1998 in China, almost 1.8 million collectively-owned enterprises currently operate and often use obsolete production technologies and pollute more than other types of firms (World Bank, 1997). The 1998 data from National Bureau of Statistics (1999) shows that the polluting industries constitute slightly more than 50 percent of GDP, so I use 0.50 for Y/L.[19] Since the magnitude of ϕ depends on the pre-existing t_L and t_Y as well as Y/L, for example, the choices for those parameters imply that $\phi =$ 0.70 for $t_L =$ 0.25 and $t_Y =$ 0.05.[20] In other words, these polluting goods are primarily manufacturing goods, so 50 percent

---

19 See Appendix 3 for the list of polluting industries.

20 Recall that ϕ is defined as $(1+t_Y)Y/(1-t_L)L$.

of total output represents almost 70 percent of private consumption of polluting manufactured goods.

For D/Y, I want an aggregate share for pollution in the dirty output. In China, many households as well as private firms still use energy-inefficient coal-burning boilers for heating. And the proportion of coal in total energy supply is estimated to drop less than 10 percentage point for the next 20 years (US DOE, 1999). Based on this evidence and the "final use" part of the 1997 input-output table from National Bureau of Statistics (1999), I calculate that the ratio of polluting inputs in total polluting output is about 55 percent. So, I use $D/Y = 0.50$ without giving false sense of precision.

Estimates for the elasticities of substitution in consumption (σ_Q) and production (σ_Y) are not available for the specific aggregation in this model. For the case of developed countries, such as the U.S., Fullerton and Metcalf (2001) and Fullerton, et al (2001) assume that both elasticities are close to one, as is broadly consistent with the empirical literature on substitution in consumption and production. However, it might be too far-fetched to assume that the situation would be the same in developing countries: much anecdotal evidence indicates that those substitution elasticities may be much lower than in developed countries. Hence, considering these factors, the baseline simulation for China is assumed here to employ 0.50 for both σ_Q and σ_Y. I also vary these numbers for sensitivity analysis later.

Finally, the model requires a measure of MED (μ). Jha and Whalley (2001) review some estimates of environmental costs in selected Asian countries. In particular, they report that China has estimated environmental costs that are 5.5 to 9.8 percent of GDP (where measured GDP includes X and Y but not Z). Unfortunately, this estimate is average damage rather than marginal damage. Moreover, their number is a more comprehensive measure than those from developed countries.[21] Hence, for the

---

[21] Unlike the studies on the environmental damages in developed countries such as Pearce and Turner (1990) on the Netherlands or Freeman (1982) on the U.S., Jha and Whalley (2001) include not only health and productivity losses from pollution in urban areas (1.7 to 2.5 percent of GDP) but also productivity

case of developing countries, I use 5 percent of GDP for the estimate of damages. Then, since Y is assumed 50 percent of GDP, damages are about 10 percent of Y. Moreover, since $D/Y = 0.50$, damages would be about 0.2 per unit of D ($\mu = 0.20$).

Table 1 summarizes the assumed parameter values for numerical simulation. The first column shows the parameter values for developing countries. The second column shows a different set of parameter values. This case represents more or less the case for developed countries: social marginal environmental damages are lower $(\mu = 0.1)$, both substitution elasticities in consumption and production are higher $(\sigma_Q = \sigma_Y = 1.0)$, marginal labor income tax rate is higher $(t_L = 0.4)$, the ratio of polluting goods to total output is lower $(Y/L = 0.3)$, and the ratio of polluting inputs to polluting output is lower $(D/Y = 0.4)$.[22] I use this alternative set of parameter values to investigate how the size of net welfare gain from using emissions taxes is changed due to various structural constraints. For a measure of welfare, I use $dU/\lambda L$, the monetary value in yuan of the change in utility as a fraction of market income.

(Insert Table 1 here.)

2. The Simulation Results

Table 2 summarizes the simulation results. The first column shows the developing country case (e.g., China). The first-best Pigouvian tax on emissions would be $\mu = 0.2$, but with a pre-existing tax on market labor $(t_L = 0.25)$, the marginal cost of public funds (Ψ) is 1.1111, and the second-best tax on emissions (t_D^*), is 18 percent from (29a). Since the pre-existing t_Y is 0.05, the second-best tax on emissions (t_D^{**}) with pre-existing t_L and t_Y is about 15 percent from (31). Furthermore, since

losses due to soil erosion, deforestation, and land degradation, water shortage and destruction of wetlands (3.8 to 7.3 percent) into the category.

[22] These parameter values for developed countries are similar to those used in Fullerton, et al (2001). The rationale for this alternative set of parameters can be found there.

$D/Y = 0.5$, equation (32b) says that the second-best tax on output (t_Y^* with $t_D = 0$) is 9 percent. Note that $t_Y^* = t_Y^{**} =$ 0.09 because the pre-existing t_D is assumed to be zero.

On the other hand, the second column shows the developed country case (e.g., the U.S.). Since $\mu = 0.1$ for this case, the first-best t_D would be 0.1. The second-best tax on emissions $\left(t_D^*\right)$ is 9.3 percent, since $\Psi = 1.0714$ with a pre-existing $t_L = 0.4$. The second-best tax on output $\left(t_Y^*\right)$ is 3.7 percent.

(Insert Table 2 here.)

The simulation results confirm the theoretical prediction in that the effects on D and Y from introducing a small t_D are greater than those from t_Y. In particular, a marginal increase in t_D reduces D by 0.33 percent for a developing country, which is more than twice the size of the decrease in D from t_Y. For a developed country, the decrease in D is greater than in a developing country mainly due to the higher substitution elasticities in production as well as in consumption. Especially, emissions (D) decrease by 0.80 percent if a developed country introduces a small t_D.

The effects on the polluting good (Y) from a marginal increase of either t_Y or t_D are different from the effects on D. In particular, introduction of a small t_Y decreases Y by the exactly same magnitudes as it decreases D in both developing and developed countries. However, the strength of t_D in reducing Y is much weaker. In both developing and developed countries, the magnitudes of reduction in Y from t_D amount to only a quarter of the magnitudes of reduction in D. This is because the change in relative input prices affects D differently than Y, when σ_Y is positive. With substitution in production, the firm can reduce D more than Y and change pollution per unit of output, by an extent that increases with σ_Y. Hence, for both developing and developed countries, the relative strength of t_D (compared to t_Y) is smaller for reducing D and Y.

The welfare gain from introducing a small t_D is *always* greater than that from a small increase in t_Y. Recall that the major strength of an emissions tax is that it provides both output and substitution effects, while the output tax only provides an output effect. For the developed country case, the welfare gain from $\hat{t}_D$ is about 50 percent larger than the gain from $\hat{t}_Y$. For the developing country case, however, the relative strength of $\hat{t}_D$ over $\hat{t}_Y$ becomes larger: 0.0143 percent, which is more than *four* times greater than the gain (0.0033 percent) from $\hat{t}_Y$.

Another interesting point is that the welfare gain from $\hat{t}_D$ is larger for a developing country than for a developed country. For example, $\hat{t}_D$ increases welfare by 0.0143 percent for a developing country but it is only 0.0096 percent for a developed country. This result is quite robust for the assumptions on some important parameters, as shown in the sensitivity analyses.

One important policy implication from this result is that the potential welfare loss from not being able to use t_D could be bigger in developing countries. The difference in the welfare gains between $\hat{t}_Y$ and $\hat{t}_D$ is 0.011 percentage points for the developing country case, while it is only 0.0036 percentage points for the developed country case. Administrative difficulties in designing and implementing a perfect emissions tax are by no means easy tasks, even in developed countries. The situations in many developing countries are worse: their institutional weaknesses such as under-funding and inexperience tend even further to limit the effective implementation of emissions taxes. The simulation results imply that the potential welfare loss from using $\hat{t}_Y$ instead of $\hat{t}_D$ might be quite big especially in developing countries.

At this point, it would be interesting to ask how the assumptions on parameters between developed countries and developing countries values affect the simulation results shown above. Table 3 shows the decomposition of the simulation results by parameter assumption. The first two columns show the base cases for developed as well as developing countries already shown in Table 2. The remaining columns show how the ‘developing countries case’ results would change as each single parameter value for the developing countries changes to that for the developed countries.

The most striking point of Table 3 is that any change in a single parameter value for the case of developing countries can bring not so much reduction in emissions and the polluting good consumption by using either t_Y or t_D. All the numbers in the first four rows show that the reduction rates in D as well as Y from the uses of t_D and t_Y in the case for developing countries are about a half (and in many cases, one third) of those in the case for developed countries. For example, the change in the substitution elasticity between clean good and polluting good to the level of developed countries $\left(\sigma_Q = 1\right)$ only reduces D by 0.3152 percent using t_Y, which is the largest effect in D for developing countries. This is only 60 percent level of the reduction in D by using t_Y (0.50 percent) for developed countries. These results strengthens the implications drawn from the numerical simulation results in that any tax policies for the purpose of environmental improvement might be limited in their scopes and effects in developing countries without the simultaneous changes in other structural factors.

First, consider the third column that reports how the base simulation results for developing countries change if labor tax rate increases to the level assumed for developed countries $\left(t_L = 0.4\right)$ from that for developing countries $\left(t_L = 0.25\right)$ with other parameter values fixed at the base case for developing countries. With higher labor income tax at 40 percent, the developing country governments still can reduce emissions and the polluting good production by introducing (or raising) either consumption tax or emissions tax. As a result, welfare improves. However, note that the numbers reported in the third column are smaller than those in the second column (the base case for developing countries) in absolute value. It means that higher labor income tax rate makes disposable income smaller and causes larger labor supply distortion, generating less effective results in both reducing emissions and the polluting good consumption and improving welfare.

(Insert Table 3 here.)

The fourth column $(t_Y = 0)$, the case that consumption tax rate is changed to zero, shows that the opposite results happen compared to the case of raising labor income tax rate. With no consumption tax, developing countries can have slightly stronger effects in reducing emissions and the polluting good consumption and in improving welfare by introducing (or raising) either consumption tax or emissions tax. It is because marginal positive change in consumption tax rate considerably decreases the polluting good consumption (-0.1667), which is almost three times bigger than the base case (-0.0670). Therefore, the size of welfare improvement from the use of consumption tax becomes much bigger in this case (0.0083) than the base case (0.0035). It also slightly increases the size of welfare improvement (from 0.0143 to 0.0167) from the introduction of emissions tax.

The fifth column, which is the case that the MEDs become smaller $(\mu = 0.1)$, shows that the effects of t_Y as well as t_D on D and Y do not change from the base case for developing countries. With low level of MEDs and nonzero consumption tax rate (i.e., $\mu = 0.1$ and $t_Y = 0.05$), additional increase of tax rates or introduction of new tax exacerbates the distortions in the economy, whereas the additional effects from environmental improvement from higher tax rates are negligible. Therefore, the welfare effects from the use of t_Y becomes negative (-0.0004). In the case of t_D, welfare increases only marginally (0.0061).

In the case of lower elasticity of market labor supply $(\varepsilon = 0.1)$, which is reported at the sixth column, the effects on pollution reduction and welfare improvement slightly increase compared to the base case for developing countries. This is due to smaller labor distortion generated with environmental taxation.

Both the seventh and eighth columns show how the base case simulation results change if the subsditution elasticity between dirty and clean inputs $(\sigma_Y = 1)$ as well as the one between polluting and clean goods $(\sigma_Q = 1)$ become larger. Note that the higher input substitutability for the polluting good (σ_Y) combined with the use of t_D can greatly reduce emissions (-0.5750), which is twice greater than the reduction rate for base case (-0.3250). On the other hand, the higher consumption goods substitutability (σ_Q) combined with the use of t_Y can greatly reduce D and Y. The changes in welfare follow the same pattern: higher σ_Y with t_D improves welfare twice greater than the base case, while higher σ_Q with t_Y shows twice bigger welfare change than the base case.

The last two (ninth and tenth) columns in Table 3 show how the simulation results change when both the ratio of the polluting industries to GDP $(Y/L = 0.3)$ and the ratio of the dirty input to the polluting good production $(D/Y = 0.4)$ become lower. If Y/L becomes lower in developing countries, the change in emissions from the use of t_Y increases. With the consumption substitutability between clean and dirty goods fixed at the base case for developing countries (i.e., $\sigma_Q = 0.5$), smaller portion of dirty good industries in GDP increases the relative strength of tax intruments in reducing pollution. Since t_Y directly affects the consumption of Y by increasing the consumer price of the polluting consumption good, the size of pollution reduction in D and Y becomes most effective when combined with the use of t_Y. The same argument can be applied to the case of lower D/Y and t_D.

3. Sensitivity Analysis

Some parameter values used in the numerical simulation are uncertain due to measurement problem. Hence, I use some alternative values for the substitution elasticities $\left(\sigma_Q \text{ and } \sigma_Y\right)$ and the elasticity of market labor supply (ε).

Table 4 and Figures 1~3 below show how the size of the welfare gains depends on the assumptions on these parameter values.

(Insert Table 4 here).

For σ_Q, the welfare gain from either $\hat{t}_Y$ or $\hat{t}_D$ increases for both developing and developed countries as the substitution ability between outputs increases. However, the gap becomes smaller as σ_Q increases. For example, the welfare gains from $\hat{t}_Y$ and $\hat{t}_D$ are same with each other when $\sigma_Q = 2.00$ for developed countries (See Figure 1). This suggests that the welfare effects from the use of the environmental output taxes could be close to the welfare gain from an ideal Pigouvian tax if the substitution in consumption is large enough. For the welfare gain from $\hat{t}_Y$ and $\hat{t}_D$ to be same with each other for developing countries, the substitution in consumption would be very large. This suggests that, if the substitutability between consumption goods is not large in developing countries, the potential welfare loss from not being able to use an ideal Pigouvian tax (and instead using consumption tax instead) would be larger than developed countries.

The welfare gain also increases as σ_Y increases. Moreover, the relative strength of $\hat{t}_D$ over $\hat{t}_Y$ becomes larger as σ_Y increases. For the extreme case, if σ_Y is very small, then the welfare gain from the use of $\hat{t}_D$ could be smaller than the welfare gain from $\hat{t}_Y$. However, the result that developing countries have larger potential welfare loss from not being able to use t_D are still valid (and even strengthened) as σ_Y increases (See Figure 2).

As the elasticity of market labor supply (ε) increases, the welfare effects slightly decrease for developing country. This is because the household decreases market labor supply due to the decrease in real wage from a marginal increase in either t_Y or t_D. Note that the size of ε has no effects on welfare for the developed country. However, this is because the developed country has no pre-existing t_Y or t_D. In this case, the effects from the changes in ε are incidentally cancelled out from both numerator and denominator in welfare expression. If t_Y is non-zero, then the welfare effects follow more or less the same pattern as in the developing country (See Figure 3).

VI. Concluding Remarks

In this paper, I use a simple general equilibrium model to examine how structural and institutional constraints might affect the relative performances of an ideal Pigouvian tax and an environmental output tax in developing countries. Although a Pigouvian tax has been shown theoretically to correct numerous environmental problems, many surveys reveal that most actual environmental taxes being used in many countries are applied to the output of a polluting industry (or to an input that is correlated with emissions).

This paper shows theoretically that a Pigouvian tax is superior to an output tax in welfare terms, because it provides the substitution effect among inputs as well as the output effect. However, the introduction of an ideal Pigouvian tax is usually not practical, due to administrative and informational problems. These problems are much more severe in developing countries. Furthermore, many developing countries suffer from other structural constraints such as high marginal environmental damages, large traditional (and often non-taxable) sectors, a larger proportion of polluting industries in total output, and many out-dated and polluting production technologies. Due to these additional constraints, developing countries might experience larger potential welfare disadvantages from not being able to use Pigouvian taxes.

With a set of parameter values from China, which is believed to have many structural characteristics in common with developing countries, this paper shows that the net welfare gain from the use of a Pigouvian tax could be *four* times larger than that of an output tax. Moreover, the potential welfare disadvantage from not being able to use an ideal Pigouvian tax is greater in developing countries than in developed countries. This result suggests that development of policy instruments that are more accurately connected to polluting behavior is more urgent in developing countries. Furthermore, this potential welfare disadvantage implies that developing countries' efforts in various structural reforms have important effects on the welfare outcomes of their environmental policies. Moreover, this welfare disadvantage does not imply that developing countries should avoid using environmental tax instruments. Although an introduction of an environmental output tax offers a smaller welfare gain in developing countries than in developed countries, the welfare gain from output tax instruments might be substantial, considering the potential savings from monitoring and enforcement activities.

My results here concern welfare cost of having no Pigouvian tax. My model evaluates the output tax as a policy that can be implemented more easily than emissions tax. For actual environmental policy, however, governments might choose CAC policy instruments rather than output tax. When ideal tax is not available, countries use other CAC rules or non-market policies. And this tendency might be stronger in developing countries. Some forms of mandate such as a quantity restriction on pollution or certain equipment requirement might be chosen instead of emissions tax. My model in this paper does not explicitly consider this point. Under competitive conditions, market-based instruments usually perform better than CAC. In the presence of market imperfections, however, the effectiveness of the different policy instruments is ambiguous (Raquate, 2005). As shown by Fullerton and Metcalf (2001), the effectiveness of welfare improving environmental policy instruments comes not from its revenue-raising property: any policy instruments that generate privately-retained scarcity rents exacerbate the pre-existing labor tax distortion. In this sense, my model can be further modified to consider what structural and institutional characteristics in developing countries are important in generating privately-held scarcity rents. In one hand, many developing countries suffer from not too transparent law-making as well as enforcement problems. For example, corruption tends to increase scarcity rents. On the other hand, any organized objections to delay adoption of market-based environmental policy instruments and to maintain scarcity rents might be weaker in developing countries. Formalization of these points into my model following Fullerton and Metcalf (2001) would be one of several possible extensions of my paper.

Other research questions not examined in this paper represent important directions for further study. First, this paper considers a tax on output of the polluting (and taxable) industry, for comparison with the ideal Pigouvian tax. However, some of the actual environmental taxes apply to an input to production that is correlated with emissions. To analyze such a tax, the model in this paper could be modified such that the polluting industry uses three inputs to production: labor, emissions, and some other input that is correlated with emissions.

I also note that this paper relies on many other standard simplifying assumptions such as a closed economy with perfect certainty and perfect competition, homogeneity among firms and households, and no trans-boundary pollution. Even though a closed economy model is an adequate representation of China, many developing countries are smaller and more open than China. On the other hand, one might vary the assumption of perfect competition, because the state and collectives own many enterprises in Chinese industry, even though their importance has been reduced.

Appendix A: Derivation of (19)

From the zero-profits condition,

$$p_Y F(L_Y,\ D) = L_Y + (1+t_D)D\,. \tag{A1}$$

Totally differentiating it:

$$F(L_Y,\ D)\,dp_Y + p_Y\left(F_{L_Y}dL_Y + F_D dD\right) = dL_Y + (1+t_D)\,dD + D\,dt_D\,.$$

Plugging the first-order conditions from the profit maximization into it:

$$Y dp_Y = D dt_D\,. \tag{A2}$$

Dividing the both sides of (A2) by p_Y gives (19).

Appendix B: Solving the system of equations

From (22) and (23), the change in labor can be derived as follows:

$$\hat{L} = \left(\frac{\varepsilon}{1 - t_L - \varepsilon t_L}\right)\left[t_Y\left(\frac{Y}{L}\right)\hat{Y} + t_D\left(\frac{D}{L}\right)\hat{D}\right]. \tag{B1}$$

Defining the elasticity of substitution between two manufactured goods (σ_Q) as $d\left(Y/X\right)\big/\left(Y/X\right)$ divided by $d\left(c_Y/p_X\right)\big/\left(c_Y/p_X\right)$, a behavioral equation can be obtained as follows:

$$\hat{Y} = \hat{X} - \sigma_Q \hat{c}_Y\,. \tag{B2}$$

Totally differentiate the household's budget constraint and use (19), (21), and (B2) to get:

$$\hat{X} = \hat{L} + \hat{w} + \phi\sigma_Q\hat{c}_Y\,, \tag{B3}$$

where $\phi \equiv (1+t_Y)Y\big/(1-t_L)L$, which is the ratio of the consumer expenditure to a polluting manufactured good to the after-tax income from market labor.

Plug (B3) into (B2), then:

$$\hat{Y} = \hat{L} + \hat{w} - \sigma_Q(1-\phi)\,\hat{c}_Y\,. \tag{B4}$$

Defining the elasticity of substitution between inputs in production of Y (σ_Y) as $d\left(L_Y/D\right)\Big/\left(L_Y/D\right)$ divided by $d\left(1/(1+t_D)\right)\Big/\left(1/(1+t_D)\right)$, a behavioral equation can be obtained as follows:

$$\hat{L}_Y = \hat{D} + \sigma_Y \hat{t}_D . \tag{B5}$$

The first-order conditions from the profit maximization imply that $dY = dL_Y + (1+t_D)dD$. Thus, the percentage change in Y can be expressed as a weighted average of the percentage changes in the two inputs:

$$\hat{Y} = \left(\frac{L_Y}{Y}\right)\hat{L}_Y + (1+t_D)\left(\frac{D}{Y}\right)\hat{D} . \tag{B.6}$$

Substitute (B5) into (B6) and use the zero-profits condition $Y = L_Y + (1+t_D)D$ at the initial equilibrium where all prices are one to get:

$$\hat{Y} = \hat{D} + \sigma_Y \left(\frac{L_Y}{Y}\right)\hat{t}_D . \tag{B7}$$

The definition of the consumer price of Y is given $c_Y = p_Y + t_Y$. Totally differentiating it,

$$\frac{dc_Y}{c_Y} = \left(\frac{p_Y}{p_Y + t_Y}\right)\left(\frac{dp_Y}{p_Y}\right) + \frac{dt_Y}{p_Y + t_Y} .$$

Since $p_Y = 1$ (but $dp_Y \neq 0$) by assumption,

$$\hat{c}_Y = \left(\frac{1}{1+t_Y}\right)\hat{p}_Y + \hat{t}_Y . \tag{B8}$$

Substituting (19) into (B8):

$$\hat{c}_Y = \hat{t}_Y + \left(\frac{1+t_D}{1+t_Y}\right)\left(\frac{D}{Y}\right)\hat{t}_D . \tag{B9}$$

Now, the equations (14), (15), (21), (23), (B2), (B3), (B5), (B6), and (B9) are a system of simultaneous equations that can be solved for the nine endogenous variables ($dU/\lambda L$, $\hat{t}_L$, $\hat{X}$, $\hat{Y}$, $\hat{D}$, $\hat{w}$, $\hat{L}$, $\hat{L}_Y$, and $\hat{c}_Y$) as functions of exogenous parameters and two exogenous policy variables, $\hat{t}_Y$ and $\hat{t}_D$. Then, for any particular policy experiment, one of these two tax rate changes will be set to zero in order to look at the effects of the other, where the change in revenue is offset by an adjustment in the labor tax t_L.

In order to solve the nine equations, they need to be reduced to fewer equations. To get the expression for the change in emissions $\left(\hat{D}\right)$, substitute (22) into (B4) and use (B1), and then:

$$\hat{Y} = \left\{ \frac{(1+\varepsilon)\,t_D\left(\frac{D}{L}\right)}{1-(1+\varepsilon)\left[t_L + t_Y\left(\frac{Y}{L}\right)\right]} \right\} \hat{D} - \left\{ \frac{\sigma_Q\,(1-\phi)\left[1-(1+\varepsilon)\,t_L\right]}{1-(1+\varepsilon)\left[t_L + t_Y\left(\frac{Y}{L}\right)\right]} \right\} \hat{c}_Y . \qquad \text{(B10)}$$

Equate (B10) with (B7) and use (B9) to get $\hat{D}$ in (24). For $\hat{Y}$ in (25), substitute (24) into (B7). Finally, for $\hat{L}$ in (26), substitute (24) and (25) into (B1).

Appendix C: The list of polluting industries

- Coal Mining and Dressing
- Petroleum and Natural Gas Extraction
- Ferrous Metals Mining and Dressing
- Nonferrous Metals Mining and Dressing
- Nonmetal Minerals Mining and Dressing
- Logging and Transport of Timber and Bamboo
- Leather, Furs, Down and Related Products
- Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products
- Furniture Manufacturing; Papermaking and Paper Products
- Petroleum Processing and Coking
- Raw Chemical Materials and Chemical Products
- Chemical Fiber; Rubber Products

- Plastic Products
- Nonmetal Mineral Products
- Smelting and Pressing of Ferrous Metals
- Smelting and Pressing of Nonferrous Metals
- Metal Products
- Transport Equipment
- Production and Supply of Electric Power, Steam and Hot Water
- Production and Supply of Gas.

References

Barthold, T. A. (1994), "Issues in the Design of Environmental Excise Taxes," *Journal of Economic Perspectives* 8: 133-51.

Baumol, W. J., and W. E. Oates (1988), *The Theory of Environmental Policy: Second Edition*, New York: Cambridge University Press.

State Administration of Taxation (SAT) (2007). "Tax System of the People's Republic of China." From the website of Beijing Local Taxation Bureau, the People's Republic of China (http://english.tax861.gov.cn/zgszky/zgszky.htm) accessed January 17, 2010.

Blackman, Allen, and Winston Harrington (2000), "The Use of Economic Incentives in Developing Countries: Lessons from International Experience with Industrial Air Pollution," *Journal of Environment and Development* 9: 5-45.

Bovenberg, A. Lans, and de Mooij (1994), "Environmental Levies and Distortionary Taxation," *American Economic Review* 84: 1085-1089.

Cremer, Helmuth, and Firouz Gahvari (2001), "Second-best Taxation of Emissions and Polluting Goods," *Journal of Public Economics* 80: 169-197.

Cropper, Maureen, and Wallace Oates (1992), "Environmental Economics: A Survey," *Journal of Economic Literature* 30: 675-740.

Earnhart, D. (2004), "The Effects of Community Characteristics on Polluter Compliance Levels," *Land Economics* 80: 408-432.

Eskeland, Gunnar (1995). *Taxing Bads by Taxing Goods*, Washington, D.C.: World Bank.

_____ and Emmanuel Jimenez (1992). "Policy Instruments for Pollution Control in Developing Countries," *World Bank Research Observer* 7: 145-169.

Eskeland, Gunnar, Emmanuel Jimenez, and Lili Liu (1998), "Prices that Clear the Air: Energy Use and Pollution in Chile and Indonesia," *Energy Journal* 19: 85-106.

Freeman, A. Myrick (1982), *Air and Water Pollution Control: A Benefit-Cost Assessment*, New York: John Wiley and Sons.

Feng, Taiwen, Linyan Sun, and Ying Zhang (2009). "The Relationship between Energy Consumption Structure, Economic Structure and Energy Intensity in China." *Energy Policy* 37: 5475-5483.

Fullerton, Don and Ann Wolverton (1999). "The Case for a Two-Part Instrument: Presumptive Tax and Environmental Subsidy." In A. Panagaria, P. Portney, and R. Schwab, eds., *Environmental and Public Economics: Essays in Honor of Wallace E. Oates*, Cheltenham: Edward Elgar.

Fullerton, Don, and Gilbert E. Metcalf (2001), "Environmental Controls, Scarcity Rents, and Pre-Existing Distortions," *Journal of Public Economics* 80: 249-267.

_____ (2002), "Cap and Trade Policies in the Presence of Monopoly and Distortionary Taxation," *Resource and Energy Economics* 24: 327-47.

Fullerton, Don, Inkee Hong, and Gilbert E. Metcalf (2001). "A Tax on Output of the Polluting Industry is not a Tax on Pollution: The Importance of Hitting the Target." in C. Carraro and G. Metcalf, eds., *Distributional and Behavioral Effects of Environmental Policy*, Chicago: University of Chicago Press.

Goulder, Lawrence H., and Roberton C. Williams, III (1999). "The Usual Excess-Burden Approximation Usually Doesn't Come Close." NBER Working Paper No. 7034, Massachusetts: NBER.

Heritage Foundation (2000). *The 2000 Index of Economic Freedom*. Washington, D.C.

Ho, Mun S., Dale W. Jorgenson, and Wenhua Di (2002). "The Health Benefits and Costs of Controlling Air Pollution in China." Mimeo, Kennedy School of Government, Harvard University.

Hoel, Michael (1998). "Emission Taxes versus Other Environmental Policies." *Scandinavian Journal of Economics* 100: 79-104.

Fisher-Vanden, Karen, and Mun S. Ho (2007). "How Do Market Reforms Affect China's Responsiveness to Environmental Policy?" *Journal of Development Economics* 82: 200-233.

Jacoby, Hanan G. (1993). "Shadow Wages and Peasant Family Labour Supply: An Econometric Application to the Peruvian Sierra." *Review of Economic Studies* 60: 903-921.

Jha, Raghbendra, and John Whalley (2001). "The Environmental Regime in Developing Countries." In C. Carraro and G. Metcalf, eds., *Distributional and Behavioral Effects of Environmental Policy*. Chicago: University of Chicago Press for NBER.

Joshi, S., R. Krishnan, and L. Lave (2002). "Estimating the Hidden Costs of Environmental Regulation." *Accounting Review* 76: 171-198.

Lai, C., C. Yang, and J. Chang (2003), "Environmental Regulations and Social Norms," *International Tax and Public Finance* 10: 63-75.

Ma, Jun (2000), *The Chinese Economy in the 1990s*. London: MacMillan.

McMorran, Ronald T., and David C. L. Nellor (1994). "Tax Policy and the Environment: Theory and Practice." *IMF Working Paper* 94-106, Washington, D.C.: IMF.

Metcalf, Gilbert E. (2008). "Environmental Taxation: What Have We Learned in This Decade?" In Alan D. Viard, ed., *Tax Policy: Lessons from the 2000s,* pp. 7-34. Washington, D.C.: The American Enterprise Institute Press.

National Bureau of Statistics (1999). *China Statistics Yearbook: CD-ROM*. People's Republic of China.

O'Connor, David (1998). "Applying Economic Instruments in Developing Countries: from Theory to Implementation." *Environment and Development Economics* 4: 91-110.

Organization for Economic Cooperation and Development (OECD) (1989). *Economic Instruments for Environmental Protection*. Paris: OECD.

_____ (1994). *Applying Economic Instruments to Environmental Policies in OECD and Dynamic Non-Member Economies*. Paris: OECD.

_____ (1995). *Environmental Taxes in OECD Countries*, Paris: OECD.

_____ (1996). Environmental *Performance in OECD Countries: Progress in the 1990s*. Paris: OECD.

_____ (1999a). *Consumption Tax Trends*. Paris: OECD.

_____ (1999b). "Economic Instruments for Pollution Control and Natural Resources Management in OECD Countries: A Survey." *OECD Working Papers* 72, Paris: OECD.

Panayotou, Theodore (1991). "Economic Incentives in Environmental Management and Their Relevance to Developing Countries." In Denizhan Erôcal ed., *Environmental Management in Developing Countries*. Paris: OECD.

Pearce, David W., and R. Kerry Turner (1990). *Economics of Natural Resources and the Environment*. Baltimore: Johns Hopkins University Press.

Pigou, Arthur C. (1932). *The Economics of Welfare (Fourth Edition)*. London: MacMillan.

Rosenzweig, Mark R. (1980). "Neoclassical Theory and the Optimizing Peasant: An Econometric Analysis of Market Family Labor Supply in a Developing Country." *Econometrica* 94: 31-55.

Russell, Clifford S., and Philip T. Powell (1996). "Choosing Environmental Policy Tools: Theoretical Cautions and Practical Considerations." Washington, D.C.: Inter-American Development Bank.

Sandmo, Agnar (1975). "Optimal Taxation in the Presence of Externalities." *Swedish Journal of Economics* 77: 86-98.

Schmutzler, Armin, and Lawrence H. Goulder (1997). "The Choice between Emission Taxes and Output Taxes under Imperfect Monitoring." *Journal of Environmental Economics and Management* 32: 51-64.

Schneider, Friedrich, and Dominik Enste (2000). "Shadow Economies around the World: Size, Causes, and Consequences." *Journal of Economic Literature* 38: 77-114.

Serôa da Motta, Ronaldo, Richard M. Huber, and H. Jack Ruitenbeek (1999). "Market Based Instruments for Environmental Policymaking in Latin America and the Caribbean: Lessons from Eleven Countries." *Environment and Development Economics* 4: 177-201.

Smith, Stephen (1996). "Taxation and the Environment." In Michael P. Devereux ed., *The Economics of Tax Policy*. London: Oxford University Press.

_____ (1997). *Evaluating Economic Instruments for Environmental Policy*. Paris: OECD.

Smulders, Sjak, and Herman R. J. Vollebergh (2001). "Green Taxes and Administrative Costs: The Case of Carbon Taxation." In C. Carraro and G. Metcalf, eds., *Distributional and Behavioral Effects of Environmental Policy*. Chicago: University of Chicago Press.

Tanzi, Vito, and Howell H. Zee (2000). "Tax Policy for Emerging Markets: Developing Countries." *National Tax Journal* 53: 299-322.

Tseng, Wanda, Hoe Ee Khor, Kalpana Kochhar, Dubravko Mihaljek, and David Burton (1994). "Economic Reform in China: A New Phase." *IMF Occasional Paper* No. 114. Washington, D. C.: IMF.

United States Department of Energy (US DOE) (1999). *International Energy Outlook* 1999, DOE/EIA-0484(99).

Vatn, Arild (1998). "Input versus Emission Taxes: Environmental Taxes in a Mass Balance and Transaction Costs Perspective." *Land Economics* 74(4): 514-25.

Winter, S. C., and P. J. May (2001). "Motivation for Compliance with Environmental Regulations." *Journal of Policy Analysis and Management* 20: 675-698.

World Bank (1997). *Clear Water, Blue Skies: China's Environment in the New Century*. Washington, D. C.: World Bank.

World Resources Institute (WRI) (1998). *World Resources 1998-99: A Guide to the Global Environment*. New York: Oxford University Press.

Yang, J., D. Cao, and D. Wang (1997), "The Air Pollution Charge System in China," in OECD ed., *Applying Market-Based Instruments to Environmental Policies in China and OECD Countries*, Paris: OECD.

Table 1: Assumptions on parameter values

Parameters		Developing Country (e.g., China)	Developed Country (e.g., the U.S.)
μ :	Social marginal environmental damage	0.20	0.10
ε :	Uncompensated elasticity of market labor supply	0.30	0.10
σ_Q :	Substitution elasticity between outputs	0.50	1.00
σ_Y :	Substitution elasticity between inputs	0.50	1.00
t_L :	Average marginal market labor income tax rate	0.25	0.40
t_Y :	Average marginal output tax rate	0.05	0.00
t_D :	Average marginal emissions tax rate	0.00	0.00
Y/L :	Ratio of polluting output to market labor	0.50	0.30
D/Y :	Ratio of emissions to polluting output	0.50	0.40

Table 2: Simulation results (in percent)

	Developing Country (e.g., China)	Developed Country (e.g., the U.S.)
Pre-existing tax rates		
t_L	25	40
t_Y	5	0
t_D	0	0
Second-best optimal tax rates		
If $t_D = 0$, then t_Y^* should be	9.00	3.73
If $t_Y = 0$, then t_D^* should be	18.00	9.33
If $t_Y = 0$ .05, then t_D^{**} should be	14.88	-
Effect on emissions (D) from		
$\hat{t}_Y$	-0.15	-0.50
$\hat{t}_D$	-0.33	-0.80
Effect on the polluting good (Y) from		
$\hat{t}_Y$	-0.15	-0.50
$\hat{t}_D$	-0.08	-0.20
Welfare effects of		
$\hat{t}_Y$	0.0033	0.0060
$\hat{t}_D$	0.0143	0.0096

Table 3: The decomposition of the simulation result by parameter assumption (in percent)

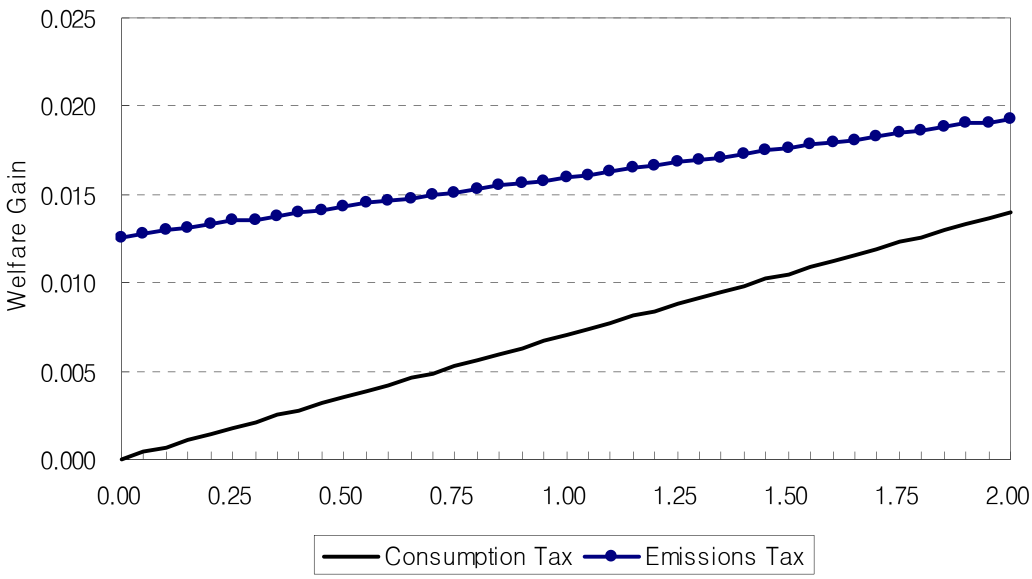
	Developed Countries (e.g., the U.S.)	Developing Countries (e.g., China)	$t_L = 0.4$	$t_Y = 0.0$	$\mu = 0.1$	$\varepsilon = 0.1$	$\sigma_Y = 1$	$\sigma_Q = 1$	$\frac{Y}{L} = 0.3$	$\frac{D}{Y} = 0.4$
Effect on emissions (*D*) from										
$\hat{t}_Y$	-0.5000	-0.1576	-0.0670	-0.1667	-0.1576	-0.1559	-0.1576	-0.3152	-0.2986	-0.1576
$\hat{t}_D$	-0.8000	-0.3250	-0.2819	-0.3333	-0.3250	-0.3242	-0.5750	-0.4001	-0.3922	-0.3600
Effect on the polluting Good (*Y*) from										
$\hat{t}_Y$	-0.5000	-0.1576	-0.0670	-0.1667	-0.1576	-0.1559	-0.1576	-0.3152	-0.2986	-0.1576
$\hat{t}_D$	-0.2000	-0.0750	-0.0319	-0.0833	-0.0750	-0.0742	-0.0750	-0.1501	-0.1422	-0.0600
Welfare effects of										
$\hat{t}_Y$	0.0060	0.0035	0.0013	0.0083	-0.0004	0.0038	0.0035	0.0070	0.0040	0.0019
$\hat{t}_D$	0.0096	0.0143	0.0133	0.0167	0.0061	0.0143	0.0270	0.0160	0.0094	0.0129

Table 4: Sensitivity analyses (in percent)

σ_Q	0.00	0.25	0.50	0.75	1.00	1.50	2.00
Developed Country (e.g., the U.S.)							
Welfare gain							
from $\hat{t}_Y$	0.0000	0.0018	0.0035	0.0053	0.0070	0.0105	0.0140
from $\hat{t}_D$	0.0126	0.0135	0.0143	0.0151	0.0160	0.0176	0.0193
Developing Country (e.g., China)							
Welfare gain							
from $\hat{t}_Y$	0.0000	0.0015	0.0030	0.0045	0.0060	0.0090	0.0120
from $\hat{t}_D$	0.0072	0.0078	0.0084	0.0090	0.0096	0.0108	0.0120
σ_Y	0.00	0.25	0.50	0.75	1.00	1.50	2.00
Developed Country							
Welfare gain							
from $\hat{t}_Y$	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
from $\hat{t}_D$	0.0017	0.0080	0.0143	0.0206	0.0270	0.0396	0.0523
Developing Country							
Welfare gain							
from $\hat{t}_Y$	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
from $\hat{t}_D$	0.0024	0.0042	0.0060	0.0078	0.0096	0.0132	0.0168
ε	0.00	0.25	0.50	0.75	1.00	1.50	2.00
Developed Country							
Welfare gain							
from $\hat{t}_Y$	0.0039	0.0036	0.0032	0.0027	0.0021	0.0000	-0.005
from $\hat{t}_D$	0.0143	0.0143	0.0143	0.0142	0.0142	0.0140	0.0135
Developing Country							
Welfare gain							
from $\hat{t}_Y$	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
from $\hat{t}_D$	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096

Figure 1: Sensitivity analysis for substitution elasticiy between outputs

Developing Countries



Developed Countries

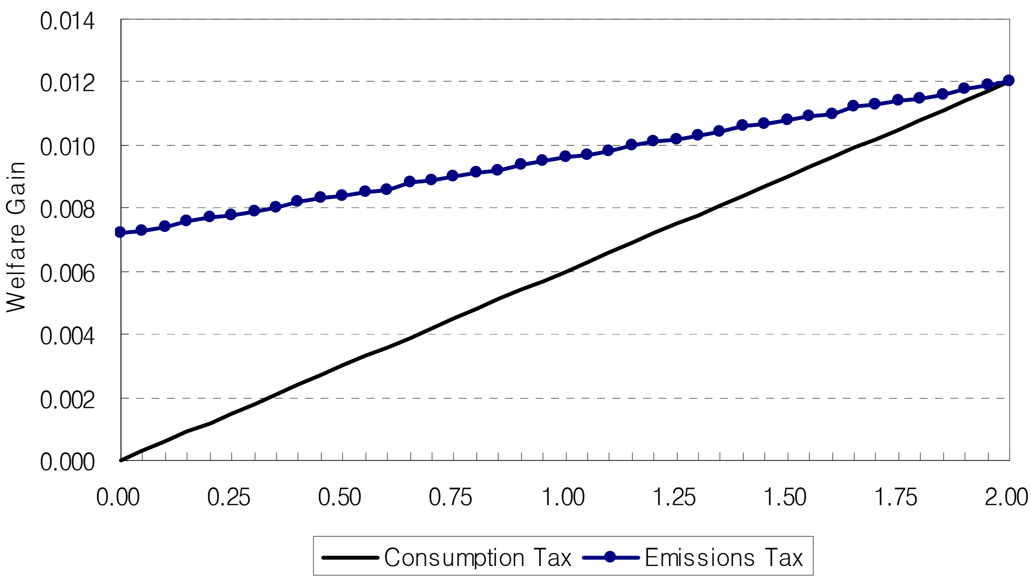


Figure 2: Sensitivity analysis for substitution elasticiy between inputs

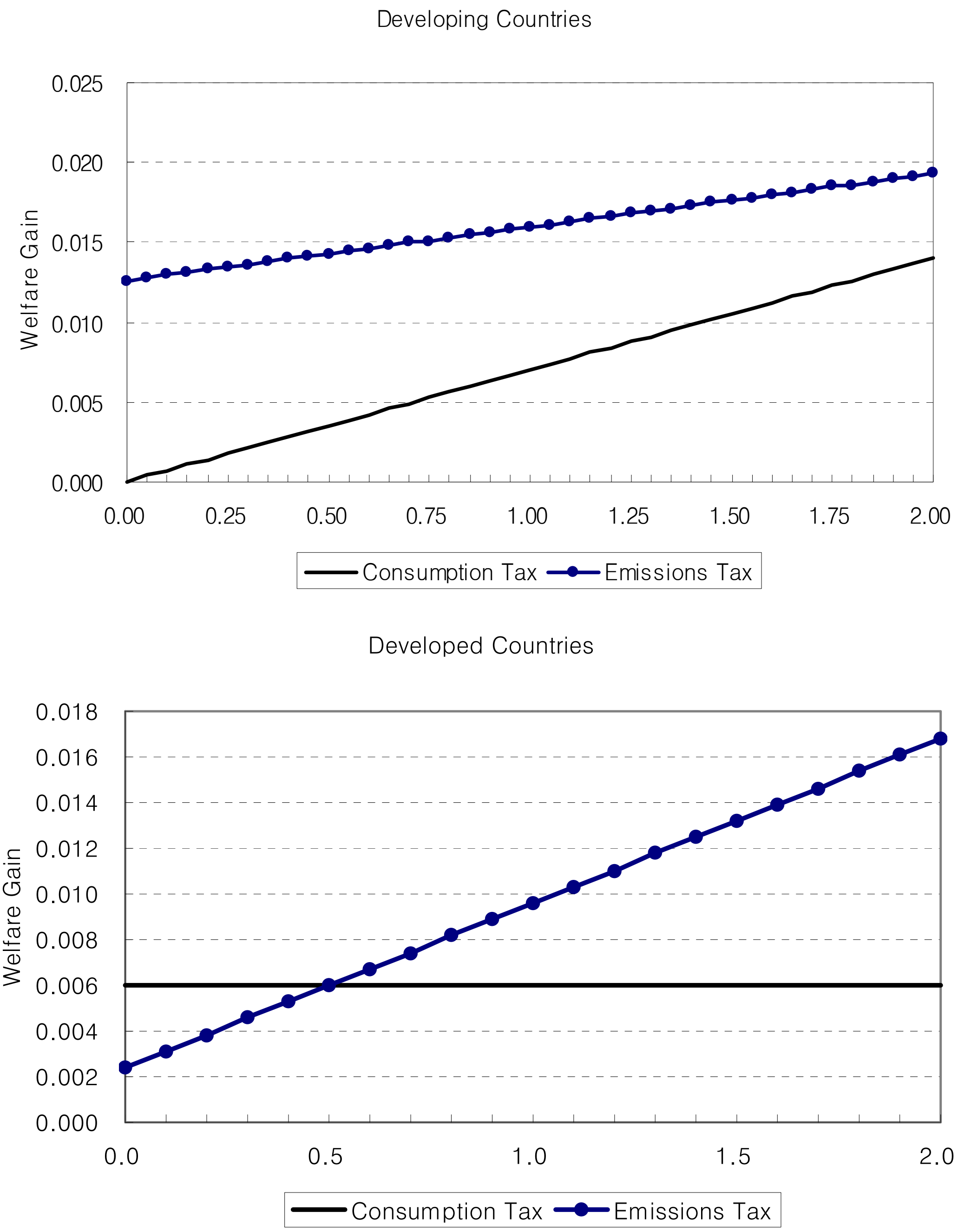
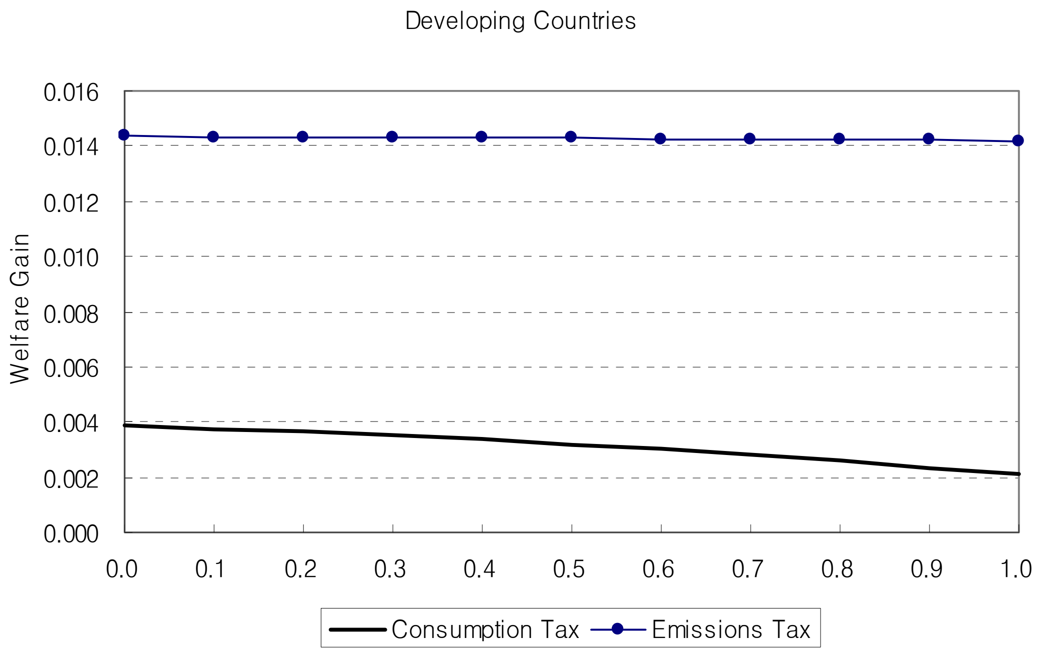
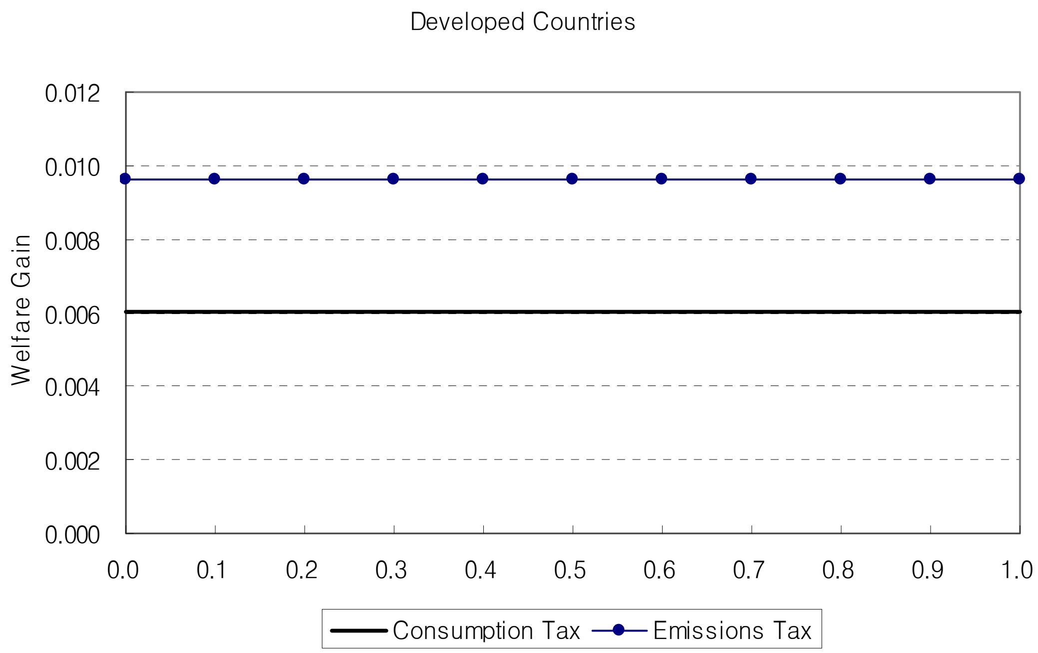


Figure 3: Sensitivity analysis for labor supply elasticiy





Dividends of Environmental Tax with Endogenized Time and Medical Expenditures

ABSTRACT

Health effects of medical expenditures deserve consideration in the literature addressing the dividends of environmental taxation, since illness not only influences utility, but also affects leisure and working time. We for the first time differentiate the health effects and tax deductibility between medical treatment expenditure and illness prevention expenditure, and redefine the marginal social damage (MSD) of dirty goods consumption that was found incorrectly measured before.

After modifying the health production function and redefining MSD, we use the traditional decomposition approach to derive a new source of dividends, named "prevention-based tax-interaction effect", that, however, is negative in sign and weakens the second dividend.

As an alternative approach, a social planning model is presented and simulation implemented. With tax neutrality, revenue raised from environmental tax is used to reduce income tax rate. The results, while confirming the first dividend, indicate that the tax reform increases neither the monetary value of utility nor labor employment. Nevertheless, an optimal bundle of income tax and environmental tax might exist that minimizes the potential welfare loss.

Dividends of Environmental Tax with Endogenized Time and Medical Expenditures

INTRODUCTION

Various factors had been considered in the literature addressing the existence of the dividends of environmental taxes through proper revenue disposal. Major determinants include product market structure (Barnett, 1980), tax-interaction effect (Bovenberg and Mooij, 1994*a*, 1994*b*; Goulder, 1995*b*; Parry, 1995; Kahn and Farmer, 1999), tax rates (Parry, 1995; Bovenberg and Goulder, 1996; Fullerton, 1997), tax base (Bovenberg and Mooij, 1994*b*; Goulder, 1995*b*; Parry, 1995), consumer's preference (Kahn and Farmer, 1999; Schwartz and Repetto, 2000; Williams, 2002, 2003; Pang and Shaw, 2007), labor market imperfection (Carraro, Galeotti and Gallo, 1996; Bosello and Carraro, 2001), role perception about the environmental tax (Goulder, Parry and Burtraw, 1997; Bovenberg, 1999; Parry and Bento, 2000; Schleiniger, 2001; Conrad and Löschel, 2005; Bento and Jacobsen, 2007), the properties of the health production function (Koç, 2007), and intertemporal welfare concern (Chiroleu-Assouline and Fodha, 2005, 2006).

Recently, health effect of medical expenditures was taken into account in this agenda, because illness not only influences utility, but also affects leisure and working time. Although the health production function is not a new concept (Grossman, 1972), the ways of its specification led to different conclusions about the components and existence of the dividends (Schwartz and Repetto, 2000; Williams, 2002, 2003; Pang and Shaw, 2007; Koç, 2007). In addition to the well-known effects such as Pigouvian effect (*PE*), revenue-recycling effect (*RE*), tax-interaction effect (*IE*), and benefit-side tax-interaction effect (IE^B), a new component named mitigation-based tax-interaction effect (IE^M) was derived when the health effect of medical expenditure was taken into account. Although not theoretically proved, IE^M was shown positive and large enough to offset IE through simulation (Pang and Shaw 2007) and, therefore, lend much support to the double dividends hypothesis.

In light of the literature, one could identify at least three critical flaws. Firstly, medical expenditure, one of the key determinants of the health production function, was usually used as a surrogate without clear functional differentiation between medical treatment and illness prevention. A distinction between the two is warranted for two reasons: (a) Medical treatment expenditure (MTE) and illness prevention expenditure (SPE) may generate different health effects. (b) While MTE is tax deductable, SPE is not in general. Secondly, the marginal social damage (MSD) of dirty goods consumption defined in many cases is limited only to the marginal disutility of illness, leaving the leisure effect unattended even though leisure time is obviously affected by illness. Some studies did consider the utility loss of leisure time (see, for example, Williams, 2003; Pang and Shaw, 2007), however, it was improperly valued. Such an incorrect measurement of MSD tends to overestimate the second dividend. Finally, marginal utility of income was assumed constant. In fact, it may change as environmental tax increased and revenue disposed.

This paper modifies the health production function by incorporating both MTE and SPE and differentiating their tax deductibility, and redefines MSD. Following similar decomposition approach, a new source of dividends with environmental tax on dirty goods, named “prevention-based tax-interaction effect” (IE^A), is derived, that, however, is negative in sign and weakens the overall second dividend. As an alternative approach, a social planning model is presented here and simulation implemented. With tax neutrality, revenue raised from environmental tax is used to reduce income tax rate. The results, while confirming the first dividend, indicate that the tax reform increases neither the monetary value of utility nor labor employment, but utility levels and leisure. Nevertheless, an optimal bundle of income tax and environmental tax might exist that minimizes the potential welfare loss.

The paper is organized as follows. An individual optimization model is presented in the second section to examine the properties of demands for clean and dirty commodities, leisure, MTE and SPE. The marginal social damage of dirty goods consumption is redefined in the third section. The fourth section demonstrates the decomposition of the dividends of environmental tax. The fifth reports a social planning model with numerical simulation results, followed by concluding remarks.

Household's Optimization

Previous literature revealed that the ways of specifying the health production function had something to do with the second dividend. Despite of its merits, the Grossman's (1972) specification was rarely adopted simply because static models are more commonly developed to examine the second dividend. In light of Schwartz and Repetto (2000) and Williams (2002), Williams (2003) created two functions to capture the health effects: health production function and illness-time function. The former, depending on medical expenditure (*M*) and environmental quality (*Q*), affects utility, while the later, depending solely on environmental quality, affects the time available for leisure and work. Pang and Shaw (2007) suggested that both functions be integrated into the illness-time function represented by $S = S(Q, M)$, where $S_Q < 0$ and $S_M < 0$, so that *M* affects utility as well as time availability. Meanwhile, the utility function, $U = U\left(v(X, Y, l), G, S\right)$, is assumed weakly separable, where v is a concave subutility function of dirty good (*X*), clean good (*Y*) and leisure time (*l*); *G* is the government expenditure on public goods, financed by labor income tax and environmental tax; and *U* is additive in *v*, *G* and *S*.

Since the second dividend is linked to the government's disposal of tax revenues, here we consider three outlets for government spending: G_a, G_b and G_c, representing, respectively, public goods, environmental protection, and direct transfer payment to households. In addition, both MTE and SPE are incorporated in a illness-time function, $S = S(Q, M, A)$ [1], where *M* and *A* represents, respectively, MTE and SPE such that $S_i < 0$, $S_{ii} > 0$ $\forall i = Q$, *M* and *A*. The environmental quality is a function of G_b and aggregate pollutant emission (*E*), i.e., $Q = Q(E, G_b)$, characterized by $Q_E < 0$, and $Q_{G_b} > 0$.

Given the budget constraint (Eq. (1)) and time constraint (Eq. (2)), the household is assumed to solve the following optimization problem:

$$\underset{\{X,Y,l,M,A\}}{Max} \quad U = U(v(X,Y,l), S(Q,M,A), G_a)$$

$$\textit{Subject to} \qquad (1+t_X)X + Y + M + (1-s)A = (1-t_L)L + G_c + t_L \cdot M, \qquad (1)$$

$$T = l + S(Q,M,A) + L \qquad (2)$$

where *T* and *L* are, respectively, time endowment and work time; t_X and t_L represent, respectively, environmental tax rate on dirty goods and tax rate on labor income; *s* is the subsidy rate on SPE; and MTE is fully deducted (amount to $t_L M$)[2].

Following conventional assumptions, prices of all commodities and labor are normalized in Eq. (2) and identical to one. Here environmental quality as well as

[1] The health effect of *M* and *A* may differ not only in quantity but also in degree of uncertainty. Uncertainty is not addressed here.

[2] Including the subsidy for SPE may sound peculiar, but provides insightful implications with respect to the second dividend, as shown later.

policy parameters is considered exogenous. Solving the above problem leads to the household demand functions of commodities, leisure time, *M* and *A*, all depending on policy parameters and government expenditures. Although it is expected that an increase in tax rates tends to reduce *X* and increase *Y*, the comparative static analysis provides no deterministic signs. The marginal effects of policy parameters on *l*, *M* and *A* are ambiguous as well since changes in policy parameters cause the budget line to shift in a unparallel manner.

MARGINAL SOCIAL DAMAGE

The marginal social damage (*MSD*) is typically defined as the marginal monetary loss of utility due to the consumption of dirty goods. Bovenberg and Mooij (1994*a*), for example, define *MSD* as:

$$MSD^B = -\left[\frac{1}{\lambda} N \frac{\partial U}{\partial Q} \frac{\partial Q}{\partial (NX)}\right], \tag{3}$$

where *N* is the total number of households and λ the marginal utility of income.

Williams (2003) and Pang and Shaw (2007) define *MSD* as equations (4) and (5), respectively.

$$MSD^W = \frac{1}{\lambda}\frac{\partial U}{\partial H}\frac{\partial H}{\partial Q} - \frac{\partial S}{\partial Q}, \tag{4}$$

$$MSD^P = -\left(\frac{1}{\lambda}\frac{\partial U}{\partial S} - 1\right)\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial X}, \tag{5}$$

where *H* represents health condition, one of the utility determinants; $Q = Q(X)$ $(= \bar{Q} - X$ in Williams 2003) and $Q_X < 0$.

Note that the first term in equations (4) and (5) represents the monetary utility loss due to illness, and the second term the opportunity cost of sickness. The common problems with equations (4) and (5) are two fold: (a) The second term is not derived directly from the associated utility function. (b) The second term implicitly assume that illness of one hour will lead to a loss of one hour available for either work or leisure (i.e., $\partial L / \partial S = \partial l / \partial S = -1$) and the normalized wage rate (= \$1) is used to value the loss of time for leisure and work due to illness. In general, this is not right since the monetary value that an individual places on leisure time may different from that on work time[3].

Accordingly, an accurate measurement of *MSD*, based on the utility function mentioned above, is expressed as follows:

$$MSD = -\frac{1}{\lambda}\left(\frac{\partial U}{\partial S} + U_v v_l \frac{dl}{dS}\right)\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial X}, \qquad (6)$$

where $dl / dS = -(1 + dL / dl) > 0$, implying $dL / dl < -1$.[4]

Equation (6) implies that *MSD*, expected to be positive in practice, will be less than those highlighted by Equations (4) and (5). The dividends will, therefore, be weakened to some extent. Furthermore, sickness time tends to change in the same direction as leisure time, but in opposite way with work time. Pang and Shaw's (2007) simulation results revealed a side-by-side increase in l and L with increasing environmental tax, that obviously violate the above conditions.

DIVIDEND DECOMPOSITION

[3] Given the utility function $U = U(v(X, Y, l), S, G)$, the marginal rate of substitution between illness and leisure is $MRS_{Sl} \equiv dl / dS = -U_S / U_v v_l > 0$. Using the time constraint, $T = L + l + S$, one obtains $dl / dS = -(1 + dL / dl) > 0$, implying $dL / dl < -1$. This implies the individual's marginal valuation of time for different purposes is different from one to the other.

[4] Totally differentiating the utility function $U = U\left(v(X, Y, l), S, G_a\right)$ and then dividing both sides by dX and λ will lead to equation (6).

To decompose the dividends, additional information other than *MSD* is required, including mainly production technology and government budget constraint. An *ad hoc* production function exhibiting constant returns to scale (see equation (7)) is imposed here, while the government budget constraint is given by equation (8).

$$\sum_i L_i = X + Y + M + A + G \qquad i = X, Y, M, A, G \tag{7}$$

$$G = t_X X + t_L (\sum_i L_i) - sA \tag{8}$$

where $G = G_a + G_b + G_c$. Note that tax revenue neutrality requires dG =0 while allowing all policy parameters to change[5].

Following the traditional approach, the dividends of environmental tax could be decomposed into several components. It can be shown that the monetary value of the marginal welfare of environmental tax is as follows (see Appendix for the proof):

$$\frac{1}{\lambda}\frac{dU}{d\tau_X} = (-\partial X / \partial t_X)\left(MSD - t_X + [1 + (1 - t_L)\frac{\partial l}{\partial S}]\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X} \right) \tag{9}$$

$$+ MWC \cdot \left(X + t_X \cdot \partial X / \partial t_X \right) \tag{10}$$

$$+ [-(MWC + 1)t_L (\partial l / \partial t_X)] \tag{11}$$

$$-[(MWC \cdot ((\partial l / \partial Q) + S_Q) + (\partial l / \partial Q)]t_L Q_E E_X (\partial X / \partial t_X) \tag{12}$$

$$+ [-t_L \cdot (1 + S_M (1 + MWC)) \cdot (\partial M / \partial t_X + M_Q Q_E E_X (\partial X / \partial t_X)] \tag{13}$$

$$+ [-(t_L S_A + s)(1 + MWC)(\partial A / \partial t_X + \partial A_Q Q_E E_X \cdot (\partial X / \partial t_X))], \tag{14}$$

where *MWC*, given by equation (15), represents the marginal welfare cost (or the excess burden) of labor income tax.

$$MWC = \Psi / \Omega > 0, \tag{15}$$

[5] It is important to distinguish ex-ante neutrality from ex-post neutrality, particularly when implementing simulations. Based on ex-ante neutrality, Pang and Shaw's (2007) simulation results did not guarantee dG =0.

where[6]

$$\Psi = t_L \cdot \left(\frac{\partial l}{t_L} + \frac{\partial l}{\partial Q} Q_E E_X \frac{\partial X}{\partial t_L} \right) + \left(MSD - t_X + [1+(1-t_L)\frac{\partial l}{\partial S}] \frac{\partial S}{\partial Q} \frac{\partial Q}{\partial E} \frac{\partial E}{\partial X} \right) \frac{\partial X}{\partial t_L}$$
$$+ [t_L \cdot (S_M + 1)] \cdot \left(\frac{\partial M}{\partial t_L} + M_Q Q_E E_X \frac{\partial X}{\partial t_L} \right) + (t_L S_A + s) \left(\frac{\partial A}{\partial t_L} + \frac{\partial A}{\partial Q} Q_E E_X \frac{\partial X}{\partial t_L} \right); \quad (16)$$

and

$$\Omega = (T - l - S) + t_X \frac{\partial X}{\partial t_L} - t_L \frac{\partial l}{\partial Q} Q_E E_X \frac{\partial X}{\partial t_L} - t_L \frac{\partial l}{\partial t_L} - t_L S_Q Q_E E_X \frac{\partial X}{\partial t_L}$$
$$- (t_L S_A + s) \left(\frac{\partial A}{\partial t_L} + \frac{\partial A}{\partial Q} Q_E E_X \frac{\partial X}{\partial t_L} \right) - t_L S_M \left(\frac{\partial M}{\partial t_L} + M_Q Q_E E_X \frac{\partial X}{\partial t_L} \right). \quad (17)$$

The RHS of equation (9) is known as the Pigouvian effect (*PE*). The component structure is different from earlier cases. Note that *PE* will be positive only when *MSD* is sufficiently large. The implication is that the first dividend might fail in case *MSD* is sufficiently small.[7]

The revenue-recycling effect (*RE*) is represented by equation (10), that is positive as predicted by previous studies, provided $\partial X / \partial t_X < 0$.

The tax-interaction effect (*IE*) is represented by equation (11). Bovenberg and Mooij (1994) pointed out that *IE* could be negative if $\partial l / \partial t_x > 0$. This is supported by the simulation results reported in Pang and Shaw (2007) and this paper, to be shown later.

The benefit-side tax-interaction effect (IE^B) is given by equation (12). According to Williams (2002, 2003), this term is in principle indeterminate in sign, depending, as

[6] Ψ and Ω represents, respectively, the marginal welfare cost and marginal tax revenue of labor income tax rate.

[7] Although not show in this paper, examples of this kind are available from the authors.

shown by equation (12), on sign{ $(\partial l / \partial Q) + S_Q$ }. In general, $\partial l / \partial Q < |S_Q|$ [8], implying a positive IE^B. On the contrary, Pang and Shaw's (2007) reported a negative value in their simulation.

The mitigation-based tax-interaction effect (IE^M), given by equation (13), differs slightly from that originally identified by Pang and Shaw (2007)[9]. Although they reported a positive value that is large enough to offset IE, IE^M is in general indeterminate in sign. It is positive only if $|S_M(1+MWC)| < 1$ and $\partial M / \partial t_X < 0$. In contrast, IE^M might become negative if the marginal productivity of the medical treatment expenditure (i.e., $|S_M|$) is sufficiently large.

The prevention-based tax-interaction effect (IE^A) is newly obtained here and given by equation (14). The effect is unambiguously negative if $\partial A / \partial t_X < 0$ and s = 0. Furthermore, IE^A is increasing in absolute value with the marginal productivity of the prevention expenditure (i.e., $|\partial S / \partial A|$). In other words, the existence of the prevention expenditure tends to reduce the overall second dividend since, just as the medical treatment expenditure could reduce sickness, so does the prevention expenditure ($\because \partial S / \partial A < 0$). Nevertheless, the subsidy to the prevention expenditure could mitigate the negative effects since the subsidy induces more A and, therefore, reduces $|\partial S / \partial A|$.

AN ALTERNATIVE APPROACH AND SIMULATION RESULTS

To facilitate simulation, a social planning approach is adopted here, in which environmental quality is endogenized through a newly specified environmental

[8] This is implied by the time constraint.

[9] The original IE^M derived by Pang and Shaw (2007) is identical to $[-t_L S_M (1+MWC) \cdot (\partial M / \partial t_X + M_Q Q_E E_X (\partial X / \partial t_X)]$, that could be positive if and only if $\partial M / \partial t_X > 0$ and sufficiently large. Nevertheless, this is rather unlikely.

quality function and an emission function, and specific functional form is specified for all relevant functions. Hence, the social planner is assumed to maximize Equation (18) subject to Equations (19) ～ (25).

(a) Utility function: $U = v - S + 10\log(G)$, [10] (18)

where $v = \left[\gamma C^{-\rho} + (1-\gamma) l^{-\rho}\right]^{-\frac{1}{\rho}}$, $C = \left[\beta X^{-\varsigma} + (1-\beta) Y^{-\varsigma}\right]^{-\frac{1}{\varsigma}}$, with parameters given as γ=0.836, ρ=-0.167, β=0.667 and ς=-0.5.

(b) Health production: $S = \dfrac{24}{1 + e^{1+0.08Q+2.7M+3.0A}}$ (19)

(c) Environmental quality function: $Q = 12 - E$ (20)

(d) Emission function: $E = X$ (21)

(e) Production function: $L = X + Y + M + A + G$ (22)

(f) Time constraint: $T = l + L + S$ (23)

(g) Tax revenues: $G = t_X X + t_L L$ (24)

(h) Household budget:

$$(1-t_L)(T - l - S) + t_L M = P_X(1+t_X)X + P_Y Y + M + (1-s)A \quad (25)$$

Simulations are conducted for the base case as well as the scenarios:

Base case: $t_L = 0.4$, $t_X = 0$, $s = 0$, $G_b = G_c = 0$, and $G = G_a = 9.178$.

Scenarios: t_X increases by an interval of 0.019 until $t_X = 0.551$, while t_L decreases at an interval of 0.005 until $t_X = 0.255$. Tax revenues, remained the same as that in the base case throughout all scenarios, are used solely for public goods.

The differences of the scenario from the base case are reported in Figure 1 for commodities, Figure 2 for time allocation and environmental quality, and Figure 3 for

[10] Adopted from Pang and Shaw (2007). Different functional forms were also considered and simulated, but not reported here.

the divergence of welfare from the base case. The findings are summarized as follows:

(a) As expected, dirty goods consumption is depressed by increasing environmental tax, while clean goods consumption decreases initially, mainly due to income effect, and eventually increases.

(b) Leisure time increases with environmental tax, while labor employment declines, consistent with the conditions associated with Equation (6). Illness time increases insignificantly, also consistent with the above expectations.

(c) Environmental quality is improved, confirming the first dividend.

(d) The difference of welfare between the base case and the scenarios is positive and increases initially with environmental tax, but begins to decline and eventually turns out to be negative when the tax rate is sufficiently high. Figure 3 indicates that there exists an optimal tax bundle (t_L^*, t_X^*) such that the welfare is maximized in the scenarios. This implies that the validity of the double dividends hypothesis to some extent depends on the tax bundle selected by the authorities.

(e) Note that the marginal utility of income (λ) decreases with environmental tax. Nevertheless, the conventional dividend decomposition approach usually assumes constant for λ. Consequently, this approach may generate estimate bias for the dividend components.

CONCLUDING REMARKS

Both medical treatment expenditure and illness prevention expenditure are pervasively observed in the real world. Their health effects are different to some extent and so is their income tax deductibility. Failure to incorporate both expenditures in addressing the dividends of environmental tax tends to be incomplete.

The marginal social damage of consuming dirty goods was neither accurately defined nor correctly measured in literature since it ignores the fact that the consumer may value time for alternative uses differently. Assuming identical valuation of time allocation may also end up with biased estimates of the second dividend.

We modifies the health production function by incorporating both medical treatment expenditure and illness prevention expenditure and tax deductibility, and redefines the marginal social damage of consuming dirty goods by incorporating both the disutility of illness and utility of leisure time. Following similar decomposition approach, a new source of dividends with environmental tax on dirty goods, named "prevention-based tax-interaction effect" (IE^A), is derived, that, however, is negative in sign and weakens overall second dividend. The mitigation-based tax-interaction effect (IE^M) might be negative as well, provided that the medical treatment expenditure being normal. In sum, whether or not the medical treatment expenditure and illness-prevention expenditure are normal goods play crucial role in signing IE^A as well as IE^M. Our model contends that both are more likely to be negative, and thus tend to weaken the overall dividends of the environmental tax on dirty goods.

Simulation results indicate that the difference of welfare between the base case and the scenarios is positive and increases initially with environmental tax, but begins to decline and eventually turns out to be negative when the tax rate is sufficiently high. Furthermore, there exists an optimal tax bundle (t_L^*, t_X^*) such that the welfare is maximized in the scenarios. This implies that the validity of the double dividends hypothesis to some extent depends on the tax bundle selected by the authorities.

While Logistic function is typically used to model the health production function (or the illness time function), it is not a good candidate when both medical treatment expenditure and illness prevention expenditure are taken into account, mainly because the marginal rate of technical substitution between the two will be constant under Logistic specification and, therefore, corner solution is inevitable. Alternative functional form deserves consideration for future studies.

Appendix: Decomposition of the dividends of environmental tax

1. Firstly, substitute the production constraint ($L \equiv \sum_i L_i = X + Y + M + A + G_a$) into time constraint $(T = l + S + \sum_i L_i,\ \ i = X, Y, M, A, G)$. Equilibrium requires $T^* = l^* + X^* + Y^* + M^* + A^* + G_a^* + S^*$. Totally differentiating T^* and assuming $dG_a = ds = 0$, one obtains:

$$
\begin{aligned}
dT^* &= \frac{\partial l}{\partial t_X}dt_X + \frac{\partial l}{\partial t_L}dt_L + \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L + \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}dt_X + \\
&\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}dt_L + \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L + \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X}dt_X + \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L}dt_L \\
&+ \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L + \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L \\
&+ \frac{\partial X}{\partial t_X}dt_X + \frac{\partial X}{\partial t_L}dt_L + \frac{\partial Y}{\partial t_X}dt_X + \frac{\partial Y}{\partial t_L}dt_L + \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L \\
&+ \frac{\partial M}{\partial t_X}dt_X + \frac{\partial M}{\partial t_L}dt_L + \frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L + \frac{\partial A}{\partial t_X}dt_X \\
&+ \frac{\partial A}{\partial t_L}dt_L + \frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}dt_X + \frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}dt_L = 0
\end{aligned}
$$

Rearranging the above equation and dividing both sides by dt_X leads to the following:

$$
\begin{aligned}
&[\frac{\partial l}{\partial t_X} + \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X} + \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X} \\
&+ \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + \frac{\partial X}{\partial t_X} + \frac{\partial Y}{\partial t_X} + \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + \frac{\partial M}{\partial t_X} \\
&+ \frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + \frac{\partial A}{\partial t_X} + \frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}] + [\frac{\partial l}{\partial t_L} + \frac{\partial l}{\partial Q}\frac{\partial Q}{E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L} \\
&+ \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L} + \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + \frac{\partial X}{\partial t_L} + \frac{\partial Y}{\partial t_L} \\
&+ \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + \frac{\partial M}{\partial t_L} + \frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + \frac{\partial A}{\partial t_L} + \frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}]\frac{dt_L}{d_X t} = 0
\end{aligned}
\qquad (A1)
$$

2. The government budget constraint is given by:

$$G = t_X X + t_L \cdot (w \cdot \sum_i L_i) - sA = t_X X + t_L w \cdot \left(T - l - S\right) - sA =$$
$$t_X X + t_L w \cdot \left(T - l - S\left(M, A, Q\right)\right) - sA$$

Totally differentiating G and imposing the revenue neutrality (i.e., $dG = 0$) to get

$$dG = Xdt_X + t_X \frac{\partial X}{\partial t_X} dt_X + t_X \frac{\partial X}{\partial t_L} dt_L + Tw \cdot dt_L + t_L w \cdot dT - l \cdot wdt_L - t_L w \frac{\partial l}{\partial t_X} dt_X$$
$$-t_L w \frac{\partial l}{\partial t_L} dt_L - t_L w \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X - t_L \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L - Swdt_L$$
$$-t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X} dt_X - t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L} dt_L - t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X$$
$$-t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L - t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X} dt_X - t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L} dt_L$$
$$-t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X - t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L$$
$$-t_L w \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X - t_L w \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L - Ads - s\frac{\partial A}{\partial t_X} dt_x$$
$$-s\frac{\partial A}{\partial t_L} dt_L - s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X - s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L = 0$$

Rearranging the above equation and divided both sides by dt_X leads to the following:

$$[X + t_X \frac{\partial X}{\partial t_X} - t_L w \frac{\partial l}{\partial t_X} - t_L w \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X} - wt_L \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$
$$-t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X} - t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - t_L w \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - s\frac{\partial A}{\partial t_X} - s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}]$$
$$+\frac{dt_L}{dt_X}[t_X \frac{\partial X}{\partial t_L} + wT - wl - wS - t_L w \frac{\partial l}{\partial t_L} - t_L w \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} - t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}$$
$$-t_L w \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} - t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L} - t_L w \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - t_L w \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$
$$-s\frac{\partial A}{\partial t_L} - s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}] = 0$$

Let $w = 1$. It is straightforward to get

$$\frac{dt_L}{dt_X} = -\frac{\phi}{\Omega}, \qquad (A2)$$

where

$$\phi = X + t_X \frac{\partial X}{\partial t_X} - t_L \frac{\partial l}{\partial t_X} - t_L \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - t_L \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X} - t_L \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$
$$-t_L \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X} - t_L \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - t_L \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} - s\frac{\partial A}{\partial t_X} - s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$\Omega = (T - l - S) + t_X \frac{\partial X}{\partial t_L} - t_L \frac{\partial l}{\partial t_L} - t_L \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} - t_L \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L} - t_L \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$
$$-t_L \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L} - t_L \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} - t_L \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} - s\frac{\partial A}{\partial t_L} - s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$

3. Totally differentiate $U^* = U\left(v(X^*, Y^*, l^*), S^*, G^*_a\right)$ to get :

$$dU^* = U_v^* v_X^* \frac{\partial X}{\partial t_X} dt_X + U_v^* v_X^* \frac{\partial X}{\partial t_L} dt_L + + U_v^* v_Y^* \frac{\partial Y}{\partial t_X} dt_X + U_v^* v_Y^* \frac{\partial Y}{\partial t_L} dt_L + U_v^* v_Y^* \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X$$
$$+U_v^* v_Y^* \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L + U_v^* v_l^* \frac{\partial l}{\partial t_X} dt_X + U_v^* v_l^* \frac{\partial l}{\partial t_L} dt_L + U_v^* v_l^* \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X$$
$$+U_v^* v_l^* \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L + U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X} dt_X + U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L} dt_L + U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X$$ 再
$$+U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X} dt_X + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L} dt_L + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X$$
$$+U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L + U_S^* \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} dt_X + U_S^* \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} dt_L$$

Divide both sides by dt_X to get

$$\frac{dU^*}{dt_X} = [U_v^* v_X^* \frac{\partial X}{\partial t_X} + U_v^* v_Y^* \frac{\partial Y}{\partial t_X} + U_v^* v_Y^* \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + U_v^* v_l^* \frac{\partial l}{\partial t_X} + U_v^* v_l^* \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}$$
$$+U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X} + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X} + U_S^* \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}] + [U_v^* v_X^* \frac{\partial X}{\partial t_L}$$
$$+U_v^* v_Y^* \frac{\partial Y}{\partial t_L} + U_v^* v_Y^* \frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + U_v^* v_l^* \frac{\partial l}{\partial t_L} + U_v^* v_l^* \frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}$$
$$+U_S^* \frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L} + U_S^* \frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L} + U_S^* \frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}]\frac{dt_L}{d_X t} \qquad (A3)$$

4. Substitute the first-order conditions into ($A3$) and divide both sides by λ to get

$$\frac{1}{\lambda}\frac{d\overset{*}{U}}{d_X t}=[(1+t_X)(\frac{\partial X}{\partial t_X}+\frac{\partial Y}{\partial t_X}+\frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+(1-t_L)\frac{\partial l}{\partial t_X}+(1-t_L)\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$+\left(1-t_L+(1-t_L)\frac{\partial S}{\partial M}\right)\frac{\partial M}{\partial t_X}+\left(1-t_L+(1-t_L)\frac{\partial S}{\partial M}\right)\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$+\left((1-t_L)\frac{\partial S}{\partial A}+1-s\right)\frac{\partial A}{\partial t_X}+\left((1-t_L)\frac{\partial S}{\partial A}+1-s\right)\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{U_S^*}{\lambda}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}]$$

$$+\frac{dt_L}{d_X t}[(1+t_X)(\frac{\partial X}{\partial t_L}+\frac{\partial Y}{\partial t_L}+\frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+(1-t_L)\frac{\partial l}{\partial t_L}+(1-t_L)\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$

$$+\left(1-t_L+(1-t_L)\frac{\partial S}{\partial M}\right)\frac{\partial M}{\partial t_L}+\left(1-t_L+(1-t_L)\frac{\partial S}{\partial M}\right)\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$

$$+\left((1-t_L)\frac{\partial S}{\partial A}+1-s\right)\frac{\partial A}{\partial t_L}+\left((1-t_L)\frac{\partial S}{\partial A}+1-s\right)\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{U_S^*}{\lambda}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}]$$

$$=[\frac{\partial X}{\partial t_X}+t_X\frac{\partial X}{\partial t_X}+\frac{\partial Y}{\partial t_X}+\frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{\partial l}{\partial t_X}-t_L\frac{\partial l}{\partial t_X}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$+(1-t_L)\frac{\partial M}{\partial t_X}+\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}+(1-t_L)\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial X}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+(1-s)\frac{\partial A}{\partial t_X}+\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X}+(1-s)\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$+\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{U_S}{\lambda}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}]+\frac{dt_L}{d_X t}[\frac{\partial X}{\partial t_L}+t_X\frac{\partial X}{\partial t_L}$$

$$+\frac{\partial Y}{\partial t_L}+\frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial l}{\partial t_L}-t_L\frac{\partial l}{\partial t_L}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-t_L\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+(1-t_L)\frac{\partial M}{\partial t_L}$$

$$+\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}+(1-t_L)\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial X}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$

$$+(1-s)\frac{\partial A}{\partial t_L}+\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L}+(1-s)\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$

$$-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{U_S^*}{\lambda}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}]$$

$$(A4)$$

5. Substitute $(A1)$ into $(A4)$ to get

$$\frac{1}{\lambda}\frac{d}{d_X}U=[\frac{\partial X}{t\partial t_X}+\frac{\partial Y}{\partial t_X}+\frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{\partial l}{\partial t_X}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}+\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$
$$+\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X}+\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{\partial M}{\partial t_X}+\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{\partial A}{\partial t_X}+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$
$$+\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}]+\frac{dt_L}{dt_X}[\frac{\partial X}{\partial t_L}+\frac{\partial Y}{\partial t_L}+\frac{\partial Y}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial l}{\partial t_L}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}$$
$$+\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L}+\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial M}{\partial t_L}+\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial A}{\partial t_L}$$
$$+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}]+[t_X\frac{\partial X}{\partial t_X}-t_L\frac{\partial l}{\partial t_X}-t_L\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}$$
$$-t_L\frac{\partial M}{\partial t_X}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$
$$-\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-s\frac{\partial A}{\partial t_X}-s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+\frac{U_S^*}{\lambda}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}+(1-t_L)\frac{\partial l}{\partial S}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$
$$-(1-t_L)\frac{\partial l}{\partial S}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}]+\frac{dt_L}{dt_X}[t_X\frac{\partial X}{\partial t_L}-t_L\frac{\partial l}{\partial t_L}-t_L\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-t_L\frac{\partial M}{\partial t_L}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_L}$$
$$-t_L\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_L}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-s\frac{\partial A}{\partial t_L}$$
$$-s\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}-\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+\frac{U_S^*}{\lambda}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}+(1-t_L)\frac{\partial l}{\partial S}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}$$
$$-(1-t_L)\frac{\partial l}{\partial S}\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}] \qquad (A5)$$

6. Substitute MSD (i.e., equation (5)) into ($A5$) to get

$$\frac{1}{\lambda}\frac{dU}{dt_X}=[(-\frac{\partial X}{\partial t_X})\left(MSD-t_X+[1+(1-t_L)\frac{\partial l}{\partial S}]\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\right)-t_L(\frac{\partial l}{\partial t_X}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})$$
$$-t_L(1+\frac{\partial S}{\partial M})(\frac{\partial M}{\partial t_X}+\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})-(t_L\frac{\partial S}{\partial A}+s)(\frac{\partial A}{\partial t_X}+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})]$$
$$-\frac{dt_L}{dt_X}[\left(MSD-t_X+[1+(1-t_L)\frac{\partial l}{\partial S}]\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\right)\frac{\partial X}{\partial t_L}+t_L\left(\frac{\partial l}{\partial t_L}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L}\right)$$
$$+t_L(1+\frac{\partial S}{\partial M})(\frac{\partial M}{\partial t_L}+\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L})+(t_L\frac{\partial S}{\partial A}+s)(\frac{\partial A}{\partial t_L}+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_L})]$$
$$(A6)$$

7. Substituting ($A2$) into ($A6$) and using MWC as defined by equation (12), one gets

$$\frac{1}{\lambda}\frac{dU}{dt_X}=[(-\frac{\partial X}{\partial t_X})\left(MSD-t_X+[1+(1-t_L)\frac{\partial l}{\partial S}]\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\right)-t_L(\frac{\partial l}{\partial t_X}+\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})$$

$$-t_L(1+\frac{\partial S}{\partial M}))(\frac{\partial M}{\partial t_X}+\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})-(t_L\frac{\partial S}{\partial A}+s)(\frac{\partial A}{\partial t_X}+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})]+MWC[X+t_X\frac{\partial X}{\partial t_X}+$$

$$-t_L\frac{\partial l}{\partial t_X}-t_L\frac{\partial l}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial t_X}-t_L\frac{\partial S}{\partial M}\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial t_X}-t_L\frac{\partial S}{\partial A}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})$$

$$-t_L\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}-s(\frac{\partial A}{\partial t_X}+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})]$$

$$=(-\frac{\partial X}{\partial t_X})\left(MSD-t_X+[1+(1-t_L)\frac{\partial l}{\partial S}]\frac{\partial S}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\right)$$

$$+MWC(X+t_X\frac{\partial X}{\partial t_X})$$

$$-(MWC+1)t_L\frac{\partial l}{\partial t_X}$$

$$-[(MWC+1)\cdot t_L\frac{\partial l}{\partial Q}+MWC\cdot t_L\frac{\partial S}{\partial Q}]\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X}$$

$$-t_L[1+\frac{\partial S}{\partial M}(1+MWC)](\frac{\partial M}{\partial t_X}+\frac{\partial M}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})$$

$$-(MWC+1)(t_L\frac{\partial S}{\partial A}+s)(\frac{\partial A}{\partial t_X}+\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial E}\frac{\partial E}{\partial X}\frac{\partial X}{\partial t_X})$$

References

Barnett AH (1980) The Pigouvian tax rule under monopoly. *American Economic Review* 70(5): 1037-1041

Bento AM and Jocobsen M (2007) Ricardian rents, environmental policy and the ‘double-dividend’ hypothesis. *Journal of Environmental Economics and Management* 53(1): 17-31

Bosello F and Carraro C (2001) Recycling energy taxes: impacts on a disaggregated labour market. *Energy Economics* 23(5): 569-594

Bovenberg AL (1999) Green tax reform and the double dividends: an updated reader’s guide. *Internal Tax and Finance* 6(3): 421-443

Bovenberg AL and Goulder LH (1996) Optimal environmental taxation in the presence of other taxes: general equilibrium analyses. *American Economic Review* 86(4): 985-1000

Bovenberg AL and Mooij RA (1994*a*) Environmental levies and distortionary taxation. *American Economic Review* 84(4): 1085-1089

Bovenberg AL and Mooij RA (1994*b*) Environmental taxes and labor-market distortions. *European Journal of Political Economy* 10(4): 655-683

Carraro, C, Gallo M, and Galeotti M (1996) Environmental taxation and unemployment: some evidence on the double dividend hypothesis in Europe. *Journal of Public Economics* 62(1-2): 141-181

Chiroleu-Assouline M and Fodha M (2005) Double dividend with involuntary unemployment: efficiency and intergenerational equity. *Environmental and Resource Economics* 31(4): 389-403

Chiroleu-Assouline M and Fodha M (2006) Double dividend hypothesis, golden rule and welfare distribution. *Journal of Environmental Economics and Management* 51(3): 323-335

Conrad K and Löschel A (2005) Recycling of eco-taxes, labor market effects and the true cost of labor: a CGE analysis. *Journal of Applied Economics* 8(2): 259-278

Fullerton D (1997) Environmental levies and distortionary taxation: comment. *American Economic Review* 87(1): 245-251

Goulder LH (1995*b*) Effects of carbon taxes in an economy with prior tax distortions: an intertemporal general equilibrium analysis. *Journal of Environmental Economics and Management*, 29(3): 271-297

Goulder LH, Parry IWH and Burtraw D (1997) Revenue-raising versus other approaches to environmental protection: the critical significance of preexisting tax distortions. *RAND Journal of Economics* 28(4): 708-731

Grossman M (1972) On the concept of health capital and the demand for health. *Journal of Political Economy* 80: 223-255

Kahn JR and Farmer A (1999) The double dividend, second-best worlds, and real-world environmental policy. *Ecological Economics* 30(3): 433-439

Koç Ç (2007) Environmental quality, medical care demand and environmental tax interactions. *Environmental and Resource Economics* 37(2): 431-443

Pang A and Shaw D (2007) Impacts of health effects on optimal environmental taxes. *Academia Economic Papers* 35(1): 1-19

Parry LWH (1995) Pollution taxes and revenue recycling. *Journal of Environmental Economics and Management* 29(3): S64-S77

Parry LWH and Brento AM (2000) Tax deductions, environmental policy, and the 'double dividend' hypothesis. *Journal of Environmental Economics and Management* 39(1): 67-96

Schleiniger R (2001) Money Illusion and the Double Dividend in the Short Run. Working Paper Series, No.93, Institution for Empirical Research in Economics, University of Zurich.

Schwartz J and Repetto R (2000) Nonseparable utility and the double dividend debate: reconsidering the tax-interaction effect. *Environmental and Resource Economics* 15(2): 149-157

Williams RC III (2002) Environmental tax interactions when pollution affects health and productivity. *Journal of Environmental Economics and Management* 44(2): 261-270

Williams RC III (2003) Health effects and optimal environmental taxes. *Journal of Public Economics* 87(2): 323-335

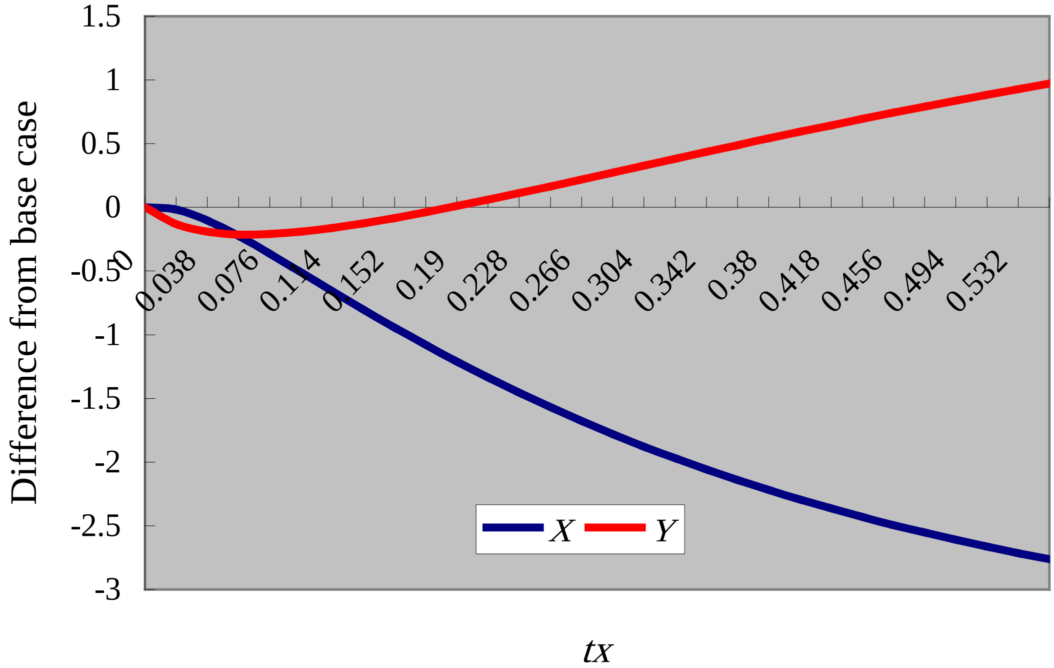


Figure 1. Effects of environmental tax on commodities: difference from base case

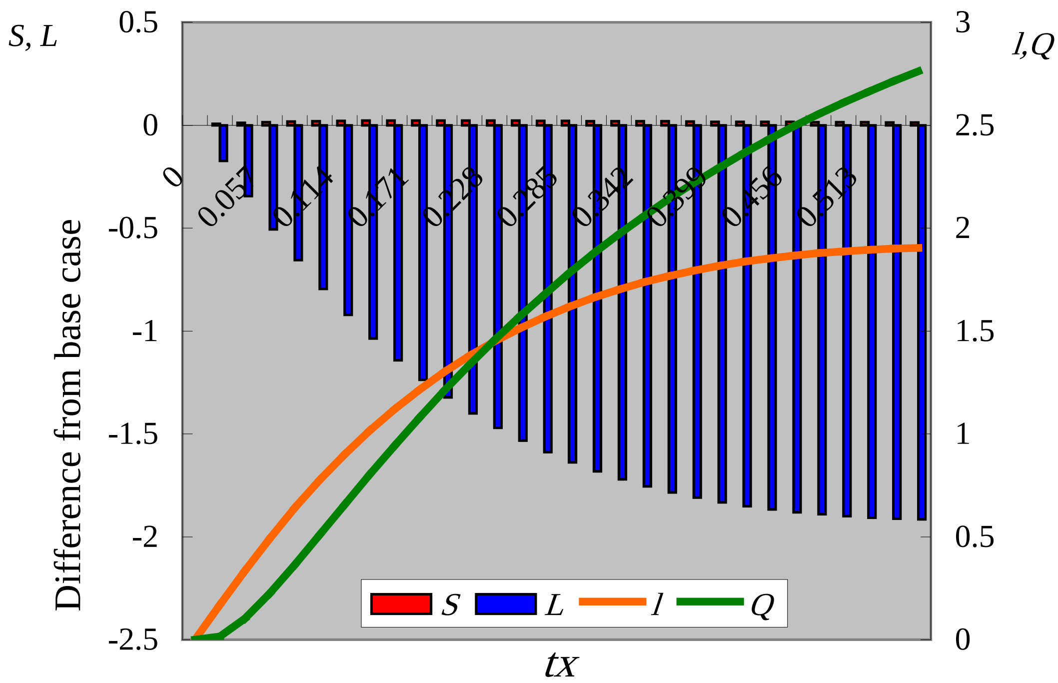


Figure 2. Effects of environmental tax on time allocation and environmental quality: difference from base case

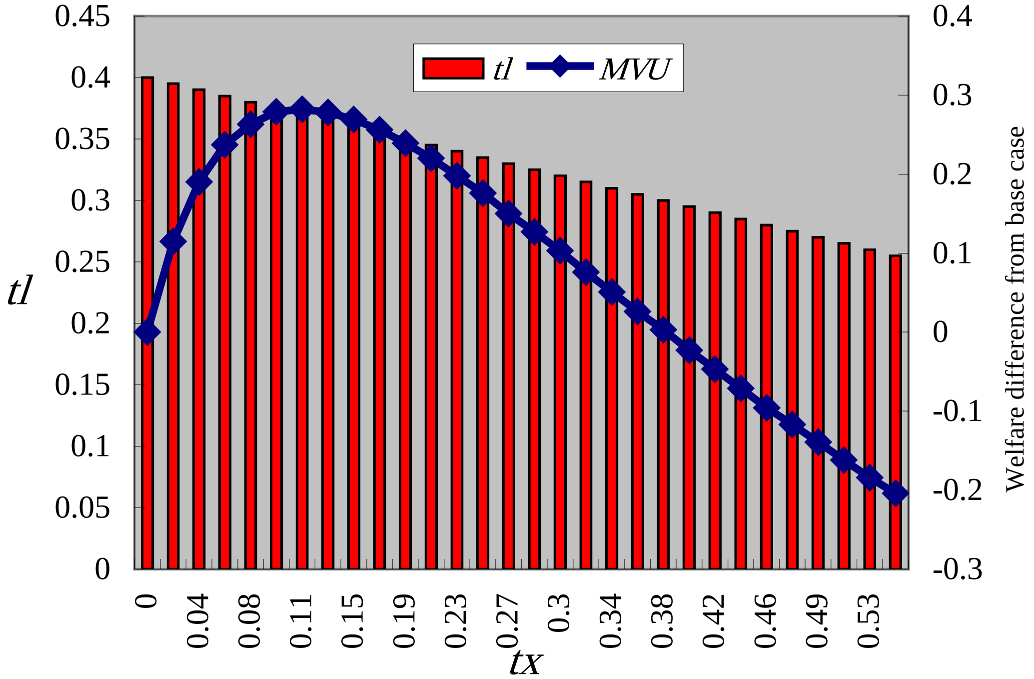


Figure 3. Effects of environmental tax on welfare: difference from base case

The Incidence of Green Tax in Korea

by

Oh Sang KWON and Deung-yong HEO[1]

August 2010

A Paper prepared for the 1st Congress of East Asian Association of Environmental and Natural Resource Economics, August 18-19, 2010, Hokkaido University, Sapporo, Japan.

1 Kwon is a professor, and Heo is a graduate student of the Department of Agricultural Economics and Rural Development at Seoul National University, San 56-1 Sillim-dong, Gwanak-gu, Seoul 151-921, Korea.
e-mail: kohsang@snu.ac.kr
phone:82-2-880-4728
Fax: 82-2-873-3565

The Incidence of Green Tax in Korea

Abstract

Introducing an incentive system of controlling CO_2 emission is a concern in Korea. The government has unveiled its policy goal of reducing 4 percent of 2005 emission. This paper investigates distributional issues of the suggested policy reform. Both an input-output model and a CGE modeling are used to anticipate the price change effects of a carbon tax system designed to be consistent with the government's policy goal. The distributional impacts of the price changes are analyzed with an estimated demand system and a consumer expenditure data set. This study finds that a carbon tax system without revenue-recycling is regressive. However, it is also found that recycling the revenue enhances income redistribution, and a lump-sum transfer of the revenue actually makes the policy reform progressive. Lower income classes may obtain net gains from carbon taxes accompanied by revenue-refund. The finding of this paper reemphasizes the importance of recycling tax revenue and a relative advantage of a tax system over a permit system in that the latter is less likely to collect substantial amount of government revenue to be recycled.

Key Words: Incidence, Carbon Tax, Revenue-recycling
JEL Classification: F1, Q4

1. Introduction

Facing the current global economic recession and increasing concerns on climate change, the Korean government has introduced a green growth policy which is called the Low Carbon, Green Growth Policy. As a part of the Policy, the Korean government unveiled a CO_2 emission limit of Korea in 2009. This was the first and the only step that the government provided the stage for public debate on the permissible levels of CO_2 consumption in the future. The business as usual (BAU) scenario of the government predicted that total CO_2 emission will increase from 594 million ton in 2005 to 888 million ton in 2030 in Korea. The cut that the Korean government presented under the BAU scenario was 30 percent reductions from the 2020 emission, and the cut amounts to a 4 percent decrease from the base year, 2005.

The reduction plan of CO_2 emission scheduled by the government has raised a concern about the policy costs. Government researchers have conducted an applied general equilibrium (CGE) analysis to anticipate the impacts of the cuts on the Korean economy (Yoo, 2009). They anticipated that the cut will result in the reduction of GDP only by 0.49 percent with the aid of appropriate reduction measures and policy instruments. However, the GDP loss may not be the only concern related to CO_2 reduction.

Reducing CO_2 emission requires an incentive policy scheme such as a carbon tax or a pollution permit system. Both schemes will affect relative prices of commodities and raise carbon price. Hence, those schemes generate not only the issue of policy cost size but also a concern about distributional aspects of the cost. Discussion on pollution control through an incentive system have traditionally focused on its efficiency effects such as social optimally or cost-effectiveness. Recently, however, distribution of policy costs is receiving increasing attentions. Distributional aspect of a policy itself is an important issue. Moreover, if the burden of a policy is uneven or unfair, then the policy may not be accepted by consumers or firms.

Various distribution issues could be involved such as incidence across income classes, burdens on consumers and producers, burdens on capital and labour, and incidence across regions. The purposes of our study are estimating and evaluating the incidence of the proposed CO_2 reduction through a carbon tax system in Korea, and providing some implications to the discussion of green tax reform. The incidence across income classes is the main concern of our paper. Our paper is not the first one investigating the issue, as shown by the literature review in Section 2, but there is no empirical work on Korea, that addresses the issue incorporating policy proposals and actual data.

We first derive the impacts of carbon taxes on commodity prices using both an input-output model and a simple computable general equilibrium (CGE) model. With the models we derive the tax rates and the tax revenues required to meet the government's policy goal. Using Consumer Expenditure Survey Data, we evaluate the incidence of carbon taxes to be introduced to cut carbon emission. The distributional impacts of recycling tax revenues will also be investigated.

2. Literature Review

The impacts of environmental policies such as carbon taxes on household income distribution have been investigated by a number of studies. Parry et al. (2005), and Fullerton and Heutel (2007) are two theoretical works on the issue, and have identified several factors of policies that affect the incidence. Our study focuses on empirical works. Among the earliest empirical works the one by Poterba (1991), who analyzed the distributional effects of a gasoline tax in the U.S. is often cited. He calculated the fractions of household income and expenditure that are used for gasoline purchase using the US Consumer's Expenditure Survey, and found that the tax is slightly regressive. Robison's (1985) even earlier work that used an input-output model found that environmental policies in general are regressive.

Most of the early studies on the incidence issue have focused only on the use-side of income: how much is the fraction of low-income consumers' income to the expenditures on regulated products? Recently, however, the source-side of income is much emphasized, and revenue-recycling or rebate became an important issue. Collected revenues may substitute for existing taxes or simply be returned to tax payers. If the way that revenues are recycled is progressive, then carbon taxes may be eventually progressive, or neutral, or at least less regressive. Revenue-recycling had attracted attentions because of its efficiency implications, i.e., green tax may enhance the efficiency of a tax system by substituting for existing distortionary taxes (e.g., Bovenberg and De Mooij 1994; Fullerton 1997; Bento and Jacobsen 2007). We emphasize that revenue-recycling can affect not only the efficiency but also the distributional aspect of a tax system.

An input-output analysis is a very natural way of deriving the economy-wide impacts of a tax or a green-budgeting policy. Many works such as Casler and Rafiqui (1993), Bull et al. (1994), Metcalf (1999), Wier et al. (2005), Hassett et al. (2009), Kim and Shin (2000), Burtraw et al. (2008) have constructed I-O models to derive the inter-industry price effects of carbon taxes or emission charges. In those works revenue-recycling can be incorporated by making the taxes or budgets revenue-neutral. Once the price change effects are measured, the relative incidences are usually calculated by combining the price change effects with the consumer expenditure data.

Input-output analyses have often been combined with micro-simulation models to analyze the incidence of carbon taxes. Hamilton and Cameron (1994), Cornwell and Creedy (1996), Labandeira and Labega (1999), and Symons et al. (1994) are the examples. In those works, once the price changes due to a carbon tax policy are estimated with an I-O analysis, then the distributional impacts are investigated with a micro-level consumer expenditure data set. They use input-output models to calculate the price changes induced by carbon taxes, and then simulate consumer's response via an estimated consumer demand system with surveyed consumption data.

Instead of an input-output analysis, a CGE model can be used to derive the price changes and investigate the distributional issue. Callan et al. (2008) provides an example. Ahmed and Cathal (2007) surveyed numerous CGE-micro-simulation models although many of them were not applied to environmental policies. Instead of combining a CGE model with a micro-simulation model, one may build a more detailed CGE model. That is, one may incorporate multiple households into CGE modeling and derive the policy incidence within the CGE model. Van Heerden et al. (2006) and Yusuf et al. (2007) are two of those more complicated works applied to carbon taxes.

There are a substantial number of works on carbon tax policies done by Korean researchers such as Lim and Kim (2010), Kim et al. (2009), and Yoo (2009), to name only a few. All those works have developed much more complicated and advanced CGE models than ours. However, there is no empirical work done on Korean environmental policy incidence yet except that of Kim and Shin (2000) who used an input-output approach to analyze only the use-side issue of income.

Our study mixes an I-O model and a CGE model with a micro-simulation approach. I-O modeling usually employs very restrictive assumptions on production technology, and the Leontief price model used to derive price changes assumes that all quantity indices are fixed in spite of the price changes. Moreover, I-O modeling has to use exogenously given demand elasticity estimates to derive the required tax rates to meet to policy goal. On the other hand, the approach is very convenient in estimating the price changes that will be induced by especially an upstream carbon tax system.

A CGE model may be a good substitute for the I-O modeling in that prices and production/consumption in both factor and output markets are endogenous as is income. Instead of using a complicated many-sector multiple-household model, we construct quite a simple and highly aggregated CGE model. Consumption goods are classified into 10 categories, and the impacts of product charges levied on commodities, determined based on each good's carbon content are analyzed within the framework of CGE. In order for a micro-simulation we estimate a 10-commodity linear expenditure system with the consumer data set, and the incidence of the policy is evaluated with the estimation results and a large scale surveyed consumption data.

Unlike the existing works that analyzed the uncompensated expenditure or income change of each consumer group induced by a carbon tax or a product charge system, we derive two compensated welfare measures, compensating variation (CV) and equivalent income explicitly[2]. The impacts of carbon taxes with and without revenue-recycling on the distribution of welfare measures are investigated.

3. Estimating a Demand System

The welfare impact of a policy change in our study is evaluated with compensated measures. Assume there are N consumption goods whose prices are p_i and whose consumption quantities are c_i (i=1,…,N). The system of expenditure equations corresponding to the demand system takes the form

$$(1)\quad p_i c_i = p_i \mu_i + \alpha_i \left(m - \sum_{j=1}^{N} p_j \mu_j \right) \quad (i=1,\dots,N), \quad \sum_{j=1}^{N} \alpha_j = 1$$

where m is disposable income or total consumption expenditure, and $\mu = [\mu_i]'$ is the n-vector of minimum consumption levels. Own price elasticities are $e_{ii} = -1 + (1-\alpha_i)(\mu_i / c_i)$ while cross price elastisticies are $e_{ij} = -\alpha_i [p_j \mu_j / p_i c_i)]$ (i≠j). All goods are gross complements but net substitutes (Johnson et al., 1984). The income elastisties are $\eta_i = -\alpha_i / s_i$ where s_i is the expenditure share, $s_i = p_i c_i / m$.

2 All the existing works except that of Cornwell and Creedy (1997) have evaluated uncompensated expenditure effects of carbon policies. Unlike our study, Cornwell and Creedy (1997) have not estimated a demand system. They obtained the required information directly from their consumption data set without any econometric estimation.

In order to derive a set of statistically reliable elasticity estimates from a data set, we need to reduce the number of elasticities by aggregating consumption items. We aggregate all consumption goods into 10 which are listed in Table 1. We followed the commodity classification of GTAP for aggregation.

The demand system is estimated with an aggregated but classified quarterly data set obtained from Consumer Expenditure Survey. In the data set households are classified into 14 groups (7 groups classified by income level and 2 groups classified by the type of major income source, wage vs. nonwage). The data cover the period between 2003 and 2009, and hence contain 392 observations. A nonlinear three stage least squares method was used to estimate the system, and the estimation results are summarized in Table 2. Almost all of the estimates are significant at 1 percent significance level.

Table 1. Commodity Aggregation

No.	Commodity categories
1	grains, other crops
2	meat, dairy, fish
3	processed food, beverages, tobacco
4	textiles, apparel, footwear
5	utilities, housing services
6	wholesale/retail trade
7	manufacturing, electronics
8	transport, communication
9	financial and business services
10	housing, education, health, public services

Table 2. Demand System Estimation Results

Parameter	Estimate	t Value	Pr > |t|	Parameter	Estimate	t Value	Pr > |t|
α_1	0.002372	6.59	<.0001	μ_1	23572.14	32.42	<.0001
α_2	0.02527	50.97	<.0001	μ_2	52850.63	17.58	<.0001
α_3	0.04851	50.66	<.0001	μ_3	137664.3	23.24	<.0001
α_4	0.082525	70.37	<.0001	μ_4	25902.99	2.67	0.0080
α_5	0.09054	59.03	<.0001	μ_5	150688.6	13.46	<.0001
α_6	0.130034	71.76	<.0001	μ_6	106417.9	6.80	<.0001
α_7	0.120112	84.89	<.0001	μ_7	60355.83	4.23	<.0001
α_8	0.195892	72.90	<.0001	μ_8	134133.1	5.69	<.0001
α_9	0.000226	7.01	<.0001	μ_9	197.0952	2.96	0.0033
α_{10}	0.304519	N/A	N/A	μ_{10}	77678.19	2.19	0.0290

4. The Impacts of Carbon Taxes

Two different approaches, an I-O modeling and a CGE model are used for deriving the price change effects of carbon taxes. In our I-O analysis carbon taxes are levied on primary energy sources; coal, crude oil, and natural gas. That is, an upstream tax system is introduced. Metcalf (2007) has argued that an upstream tax system has a strong advantage in that its administrative burden is relatively very small. No acting carbon regulation has been introduced in Korea yet, and we have to determine the optimal tax rate that will achieve the government's target level of CO_2 reduction. An I-O analysis *per se* does not provide any direct information on the optimal tax rate since its price model assumes that all quantity indices are fixed. That is, an I-O analysis derives the change in commodity prices induced by carbon taxes but assumes that all quantities do not change despite of the prices changes. In order to resolve this problem of an I-O analysis, we combine the estimated linear expenditure demand system with the I-O price model, and derive the quantity changes and thereby the carbon-emission change of the economy. Our analysis follows the following steps:

Stage 1: Assume a rate of carbon tax and derive the change in commodity prices using the I-O table.

Stage 2: Apply the predicted price changes into the demand system and derive the changes in each consumption quantity and carbon emission.

Stage 3: Repeat Stage 1 and 2 until the change in total carbon emission meets the target level.

Stage 4: Apply the final prices into the estimated demand system and Consumer Expenditure Survey Data, and evaluate policy incidence.

We use the 2007 Input-output table; 2007 is the base year. The target level of reduction is the 4 percent decrease from the 2005's emission. The target, which is almost equivalent to an 8 percent reduction from the emission of 2007, is assumed to be met in 2007 instantaneously. All coefficients in the I-O table are transformed into carbon units using the IPCC carbon emission coefficients and the Energy I-O Table of Korea.

The national account of the I-O table implies that

(2) $(I - A')P_0 = V$

where I is and N-identity matrix, A is an N-matrix with elements a_{ij}, P_0 is an N-vector of industry prices, and V is the N-vector of value-added ratios. The system can be solved for the price vector:

(3) $P_0 = (I - A')^{-1} V$

Now let t_{ij} be a unit tax on the use of primary energy i by industry j imposed due to the new carbon tax system. Then the new system under the carbon tax can be solved as:

(4) $P_1 = (I - B')^{-1} V$

where B is an N-matrix with elements $(1+t_{ij})a_{ij}$. P_1 is the new price vector, which is the result that Stage 1 obtains. In the Korean Energy I-O table grain is not discriminated from meat and dairy products. Hence, our I-O model combines sector 1 and 2, and is a 9- sector model.

Table 3. Price Changes Induced by Carbon Taxes

Commodity Group	I-O (%)	CGE (%)
1, 2	2.1	3.2
3	2.0	1.0
4	3.4	1.4
5	12.3	64.5
6	1.6	1.1
7	8.0	24.5
8	6.5	8.6
9	0.6	0.7
10	1.3	1.3
Tax Rate (Won/CO_2 ton)	36,545	44,222
Tax Revenue (billion Won)	26,079	21,384

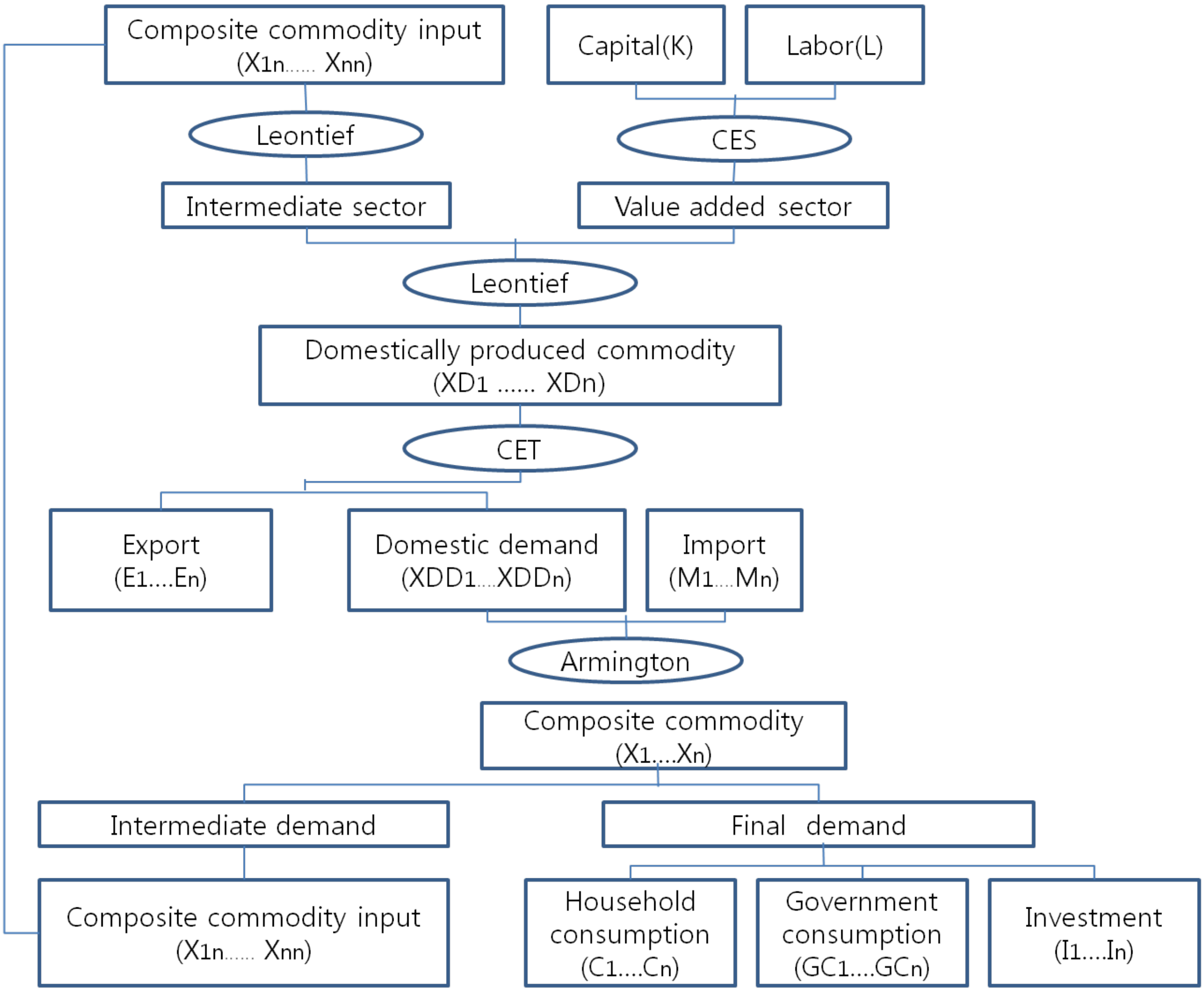
The results of our I-O analysis in Table 3 suggest that an upstream carbon tax equivalent to 36,545Won per ton of CO_2 emission needs to be imposed to meet the government's target. This finding is quite interesting because the tax rate is similar to the current permit trading price in the EU ETS which is about 20 Euros (1 Euro is 1,520 Won as of July 9, 2010). All the prices will increase, and the price in the utilities industry will increase by more than 12 percent by carbon taxes. Prices in the manufacturing & electronics sector, and transportation and communication sector will also increase substantially. It is anticipated that 26,079 billion Won will be collected as a carbon-tax-revenue, and that amounts to about 16 percent of the government's current total tax revenue.

Our CGE model also has the same 9 sectors and 1 household. Again, the household's utility function has a linear expenditure type. We calibrate parameters of the demand system using the income elasticities and the Frisch parameter which is the expenditure elasticity of the marginal utility of expenditure, obtained from the estimates in Table 1. Domestic goods are produced with intermediate inputs and value-added, which are combined through a Leontief production function. Value-added function is a constant elasticity of substitution (CES) function of capital and labor. Produced domestic outputs are transformed into exports and domestic goods according to a constant elasticity of transformation (CET) function. The final composite commodities are produced with domestic goods and imports under the condition of a CES function (an Armington assumption). The elasticities of the CES and CET functions are obtained from Shin (1996), Deardorff and Stern (1986), Melo and Tarr (1992), and the GTAP database.

Both household and the government make savings, and the household's marginal propensity to saving is assumed to be fixed. The government collects income and product charges, and allocates the tax revenue into government's spending, saving and transfers to the household maximizing a Cobb-Douglas utility function. The government levies product charges based on each commodity's carbon contents. Hence, it employs a downstream carbon tax. A downstream tax is more appropriate for our 9-sector CGE model where the structure of energy input use is not specified in detail.

There is a 'bank' that allocates household saving, government saving and foreign saving over the investment demand maximizing another Cobb-Douglas utility function. The model is static, and hence, capital supply is assumed to be fixed. Labor supply is also fixed, but labor employment is affected by the change in wage rate relative to price index through a Phillips curve. Figure 1 illustrates the structure of our CGE model.

Figure 1. Structure of the CGE Model



There are two issues involved in interpreting the price changes derived by the CGE model, which were not addressed seriously by existing literature. First, one of the input or output prices, or a function of the prices is fixed in the model because of the homogeneity property of the general equilibrium price system, and hence, we can derive only relative price changes. Second, consumer income as well as commodity prices changes due to the product charges levied for CO_2 reduction. These two properties of the policy simulation make difficult to evaluate the welfare impacts of policy. We circumvent those two issues by restricting household's income expenditure to be fixed, which is a function of primary input prices. Keeping disposable income at a constant level despite of imposing product charges will accelerate the increase in commodity prices required to meet the policy target.

The policy simulation results with our CGE model are also summarized in Table 3. Compared to the results from the I-O analysis, the change in prices is quite uneven. Again, all commodity prices increase due to the carbon-based product charges, but prices of two carbon-intensive sectors (sector 5 and 7) increase much more than the other prices. In the I-O model where carbon taxes are levied on the primary energies which are used as intermediate inputs, taxes are passed along as intermediate price increases to all sectors, which in turn pass on these increases by raising their output prices accordingly, etc. On the other hand, in the CGE model, taxes are imposed only at the final stage of consumption, and hence the tax rates or rates of price increases vary much more across sectors. Total tax revenue required to meet the target level of reduction, obtained from the CGE model is slightly smaller than that from the I-O model.

Table 4 summarizes the changes in major economic indicators that will be caused by the product charges impose in the CGE model.

Table 4. The Impacts of Carbon-based Product Charges

Indicator	Change Rate (%)	Indicator	Change Rate (%)
Labor Price	0.0	Total Saving	0.2
Capital Price	1.2	Export	-1.00
Exchange Rate	0.3	Unemployment Rate	4.03 (from 3.00)
Commodity Price Index	5.3	Value Added	0.0

5. The Incidence of Carbon Taxes

We measure the welfare effects of imposing carbon taxes using compensating variation (CV) which is a path-independent compensated welfare measure. The indirect utility function corresponding to the linear expenditure system in (1) is

$$\textbf{(5)}\quad v(p,m)=\frac{m-\sum_{j=1}^{N}p_j\mu_j}{\prod_{j=1}^{N}(p_j)^{\alpha_j}}\ .$$

If a policy induces a change in prices and income from (p^0, m^0) to (p^1, m^1), then the corresponding measure of compensating variation is

$$\textbf{(6)}\quad CV=m^1-\sum_{j=1}^{N}p_j^1\mu_j+\left[m^0-\sum_{j=1}^{N}p_j^0\mu_j\right]\prod_{j=1}^{N}(p_j^1/p_j^0)^{\alpha_j}\ .$$

Using the actual income distribution in the consumer survey data of 2006 which has 90,696 observations, we derive the welfare measure for every consumer household. All prices and income data are evaluated with 2007 prices. We want to interpret CV as a cost-measure of the policy. Hence we take the minus of CV (= -CV) to investigate policy incidence.

Table 5 summarizes the results for the case where additional tax revenue is not returned to households, i.e., revenue is not recycled. The government simply saves or expenses the tax revenue, and hence, m^1 is equal to m^0 in (6). In the CGE model, where a downstream product-charge-type tax system was introduced holding disposable income at a constant, prices of household utilities and transportation whose budget shares are relatively large increase much more than in the I-O model. Thus, household's welfare loss is larger in the former.

Table 5. Welfare Loss of Carbon Taxes million Won/household (per month)

Model	Mean	Std. Dev.	Min	Max
I-O (upstream)	90,607	79,093	7,305	3,001,141
CGE (downstream)	243,469	182,493	51,264	6,959,037

-CV is an increasing transform of income, and hence, taking the ratio of -CV to household consumption expenditure, -CV/m, may provide an appropriate measure of cost incidence. Figures 2.a and 3.a illustrate the relationships between -CV/m and m under the two policy scenarios. The policy effects are clearly regressive in both cases.

Figures 2.b and 3.b show the cases where tax revenue is recycled in a way to give a uniform lump-sum transfer to all households. Total tax revenue is divided by the number of households to determine the amount to be returned to each household. Now m^1 in (6) is the sum of m^0 and the amount returned to each household. The new measure of burden, which is -CV/m, is now an increasing function of m, and the lump-sum transfer makes the policy very progressive. In fact, a substantial number of low income households are getting welfare gains not losses since the amounts returned to them are larger than their expenditure increases caused by price changes[3].

Finally, Figures 2.c and 3.c show the distributional effects of carbon taxes when the government cuts general *ad valorem* tax rates for all commodities uniformly to return the tax revenue. For a complete revenue-recycling, the general tax rates need to be reduced by 4.27 percent for the I-O model and by 3.50 percent for the CGE model, respectively. The policy costs become regressive again. The impact of cutting general tax rates for all commodities maintaining a carbon tax is not large enough to make the carbon tax system progressive.

3 There may be a rebound or feedback effect since the lump-sum transfer will increase households' income and make them consume more goods and carbon. If we rerun a CGE policy simulation with the lump-sum transfer, then we estimate a rebound effect of 18 percent. We do not take into account this feedback effect. If we want to incorporate this rebound effect into deriving the optimal charge rate, then we have to impose higher charge rates than the ones that resulted in price changes in Table 2. Our conclusions below will be still valid even in that case.

Figure 2. Incidence of Policy Simulations: I-O Model (Upstream Taxes)

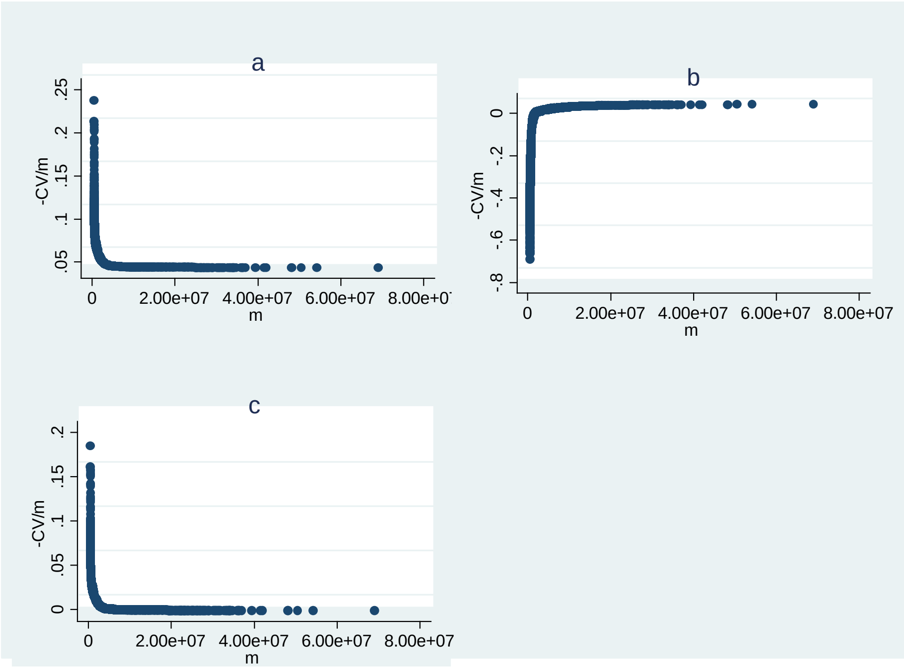
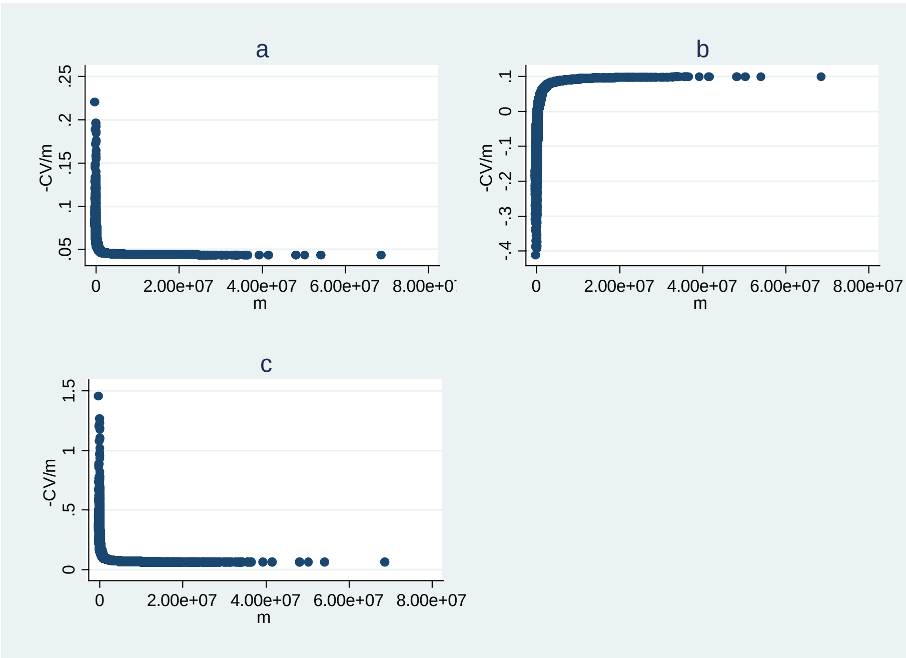


Figure 3. Incidence of Policy Simulations: CGE Model (Downstream Taxes)



Figures 2.b and 3.b have demonstrated that a lump-sum transfer of carbon tax revenue may make the policy cost more progressive. Only the cost burdens were compared by the figures. It is not certain yet whether the policy generates a more progressive income distribution or not. In order to figure out a complete income distribution effect we may need to use an inequality index such as the Gini index. A generalized entropy (GE) measures is one of those inequality indices, whose general formula is (Haughton and Khandker, 2009)

$$(7) \qquad CE(\varepsilon)=\frac{1}{\varepsilon(\varepsilon-1)}\left[\frac{1}{N}\sum_{i=1}^{I}\left(\frac{m_i}{\overline{m}}\right)-1\right].$$

where $\overline{m}$ is mean income per person. We choose ε = 0, and values of GE(0) vary between zero and infinity, with zero representing an equal distribution and higher values representing higher levels of inequality. GE(0) cannot be applied to –CV/m which has negative values for many individuals when carbon tax revenue is returned.

Let m^1 be the income allowed after introduction of the policy (and recycling of revenue) and m^0 be the income without the policy. Substituting the distributions of m^1 and m^0 separately into the formula in (7) may not be a legitimate way of investigating the policy's impact on income distribution because those two income distributions are obtained with different commodity prices, and hence, households face different consumption possibilities. Using the equivalent income introduced by King (1983) can be a useful alternative. Denote a reference price vector by p^R. For a budget constraint (p, m), "equivalent income is defined as that level of income which, at the reference price vector, affords the same level of utility as can be attained under the given budget constraint (King, p. 188)":

$$(8) \quad v(p^R, m_E) = v(p, m)$$

Inverting the indirect utility function gives us the equivalent income function:

$$(9) \quad m_E = f(p^R, p, m)$$

Let p^R be the original price vector p^0. Then the equivalent income of the initial budget constraint (p^0, m^0) becomes just the observed initial income, f(p^0, p^0, m^0) = m^0. If the budget constraint is the post-policy one, then the equivalent income is $f(p^0, p^1, m^1)$. Note $m_E = e(p^R,v)$, which is an expenditure function. Hence, $f(p^0, p^1, m^1) - f(p^0, p^0, m^0) = f(p^0, p^1, m^1) - m^0 = e(p^0,v^1) - e(p^1,v^1) + m^1 - m^0$, which is the EV (equivalent variation) of the policy change. Thus, the equivalent income itself is anther compensated measure of welfare. With a linear expenditure system, the equivalent income is calculated by the formula:

$$(10)\quad m_E = \sum_{j=1}^{N} p_j^0 \mu_j + \prod_{j=1}^{N} (p_j^0 / p_j^1)^{\alpha_j} \left[m^1 - \sum_{j=1}^{N} p_j^1 \mu_j \right]$$

Table 6 summarizes the GE(0) measures of equivalent income under various scenarios. The data of 90,696 observations were used. In the CGE model 12 households showed negative equivalent income when there is no revenue-recycling, and were deleted from GE(0) calculation. As confirmed by Figures 2.a and 3.a, carbon taxes without revenue-recycling are substantially regressive. If the tax revenue is returned to households as a lump-sum transfer, then income distribution is more progressive than that of the initial income without any policy. That is, a carbon tax accompanied by a lump-sum transfer actually contributes to the equality of income distribution. Finally, cutting general *ad valorem* tax rates for all commodities uniformly to return the tax revenue also makes income distribution more progress in that it generates a GE(0) measure smaller than that of a carbon tax without any revenue-recycling. However, the impact of this kind of revenue-recycling is not strong enough to make the distribution of income more equal than that of the initial no-carbon-policy income.

Table 6. GE(0) Measures of Equivalent Income Distribution

	I-O Model	CGE Model
No Carbon Policy	0.2698	0.2695
Carbon Tax without Revenue Recycling	0.2723	0.2917
Carbon Tax with a Lump-Sum Transfer	0.2259	0.2461
Carbon Tax with a Commodity Tax Reduction	0.2722	0.2912

6. Summary and Conclusion

Introducing an incentive system of controlling CO_2 emission is a concern in Korea. The government has unveiled its policy goal of reducing 4 percent of 2005 emission. This paper investigates distributional issues of the suggested policy reform. Both an input-output model and a CGE model are used to anticipate the price change effects of a carbon tax system designed to be consistent with the government's policy goal. The distributional impacts of the price changes are analyzed with an estimated demand system and a consumer expenditure data set.

This study finds that a carbon tax system without revenue-recycling is regressive. However, it is also found that recycling the revenue enhances income redistribution, and a lump-sum transfer of the revenue actually makes the policy reform progressive. Lower income classes may obtain net gains from carbon taxes accompanied by revenue-refund. The finding of this paper reemphasizes the importance of recycling tax revenue and the relative advantages of a tax system over a permit system in that the latter is less likely to collect substantial amount of government revenue to be recycled.

References

Ahmed, V. and O. Cathal (2007), *CGE-Microsimualtion Modelling: A Survey*, Munich Personal RePEc Archive (MPRA) Paper No. 9307.

Bento, A. M. and M. Jacobsen (2007), "Ricardian Rents, Environmental Policy and the 'Double-Dividend Hypothesis," *Journal of Environmental Economics and Management* 53: 17-31.

Bento, A. M., L. H. Goulder, E. Henry, M. R. Jacobsen, and R. H. von Haefen (2005), "Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-market Study," *American Economic Review* 95: 282-287.

Bovenberg, L. A. and R. A. De Mooij (1994), "Environmental Levies and Distortionary Taxation," *American Economic Review* 84: 1085-1089.

Bull, N., K. Hassett, and G. Metcalf (1994), "Who Pays Broad-Based Energy Taxes? Computing Lifetime and Regional Incidence," *The Energy Journal* 15: 145-164.

Burtraw, D., R. Sweeney, and M. Walls (2009), "The Incidence of U.S Climate Policy: Where You Stand Depends on Where You Sit," RFF DP 08-28, Resources for the Future.

Callan, T., S. Lyons, S. Scott, R. S. J. Tol, and S. Verde (2008), "The Distributional Implications of a Carbon Tax in Ireland," ESRI Working Paper No. 250.

Casler, S. D. and A. Rafiqui (1993), "Evaluating Fuel Tax Equity: Direct and Indirect Distributional Effects," *National Tax Journal* 56: 197-205.

Cornwell, A. and J. Creedy (1996), "Carbon Taxation, Prices and Inequality in Australia," *Fiscal Studies* 17: 21-38.

Cornwell, A. and J. Creedy (1997), "Measuring the Welfare Effects of a Tax Changes Using the LES: An Application to a Carbon Tax," *Empirical Economics* 22: 589-613.

De Melo, J. and D. Tarr (1991), *A General Equilibrium Analysis of US Foreign Trade Policy*, MIT Press.

Deardorff, A. V and R. M. Stern (1986), *The Michigan Model of World Production and Trade*, Cambridge University Press.

Fullerton, D. (1997), "Environmental Levies and Distortionary Taxation: Comment," *American Economic Review* 87: 245-251.

Fullerton, D. and G. Heutel (2007), "The General Equilibrium Incidence of Environmental Taxes," *Journal of Public Economics* 91: 571-591.

Hamilton, K. and G. Cameron (1994), "Simulating the Distributional Effects of a Canadian Carbon Tax," *Canadian Public Policy* 20: 385-399.

Hassett, K. A., A. Mathur, and G. E. Metcalf (2009), *The Consumer Burden of a Carbon Tax on Gasoline*, AEI Working Paper #147.

Haughton, J. and S. R. Khandker (2009), *Handbook on Poverty + Inequality*, The World Bank.

Johnson, S. R., Z. A. Hassan, and R. D. Green (1984), *Demand System Estimation: Methods and Applications*, Ames, The Iowa State University Press.

Kim, I.-C. and D.-C. Shin (2000), "The Distribution of Pollution Abatement Costs among Income Classes in Korea," *Environmental and Resource Economics Review* 9: 545-562.

Kim, S., G. L. Cho, and S. J. Yoo (2009), "An Economic Impact Analysis of the Post-2012 Policy Portfolio, Utilizing the Global Dynamic CGE Model," *Environmental and Resource Economics Review* 18: 587-636.

King, M. A. (1983), "Welfare Analysis of Tax Reforms Using Household Data," *Journal of Public Economics* 21: 183-214.

Labandeira, X. and J. M. Labeaga (1999), "Combining Input-Output Analysis and Micro-Simulation to Assess the Effects of Carbon Taxation on Spanish Households," *Fiscal Studies* 20: 305-320.

Lim, J.-S., and Y.-G. Kim (2010), "Revenue Neutral Introduction of Carbon Tax and Double-Dividend Effect on the Korean Economy," *Environmental and Resource Economics Review* 19: 45-80.

Metcalf, G. E (1999), "A Distributional Analysis of Green Tax Reforms," *National Tax Journal* 52 (4): 655-682.

Metcalf, G. E. (2007), *A Proposal for a U.S. Carbon Tax Swap: An Equitable Tax Reform to Address Global Climate Change*, The Brookings Institution.

Parry, I. W. H., H. Sigman, M.Walls, and R. C. Williams III (2005), *The Incidence of Pollution Control Policies*, NBER Working Paper 11438.

Poterba, J. M. (1991), "Is the Gasoline Tax Regressive?" NBER Working Paper No. 3578.

Robison, D. H. (1985), "Who Pays for Industrial Pollution Abatement?" *Review of Economics and Statistics* 67: 702-706.

Shin, D.-C. (1996), "Elasticity of Substitution between Imported Goods and Domestic Goods," *Korean Economic Review* 44: 101-118.

Symons, E., J. Proops, and P. Gay (1994), "Carbon Taxes, Consumer Demand and Carbon Dioxide Emissions: A Simulation Analysis for the UK," *Fiscal Studies* 15: 19-43.

Van Heerden, J. R. Gerlagh, J. Blignaut, M. Horridge, S. Hess, R. Mabugu, and M. Mabugu (2006), “Searching for Triple Dividends in South Africa: Fighting CO2 Pollution and Poverty While Promoting Growth,” *The Energy Journal* 27: 239-251.

Wier, M., J. Birr-Pedersen, H. K. Jacobsen, and J. Klok (2005), “Are CO2 Taxes Regressive? Evidence from the Danish Experience,” *Ecological Economics* 52: 239-251.

Yoo, S. J. (2009), “National Strategies to Reduce Climate Change Gases,”, mimeo

Yusuf, A. A. and B. Resosudarmo (2007), “On the Distributional Effect of Carbon Tax in Developing Countries: The Case of Indonesia,” Working Paper in Economics and Development Studies, Center for Economics and Development Studies, Padjadjaran University.

Recycling, Trade in Recyclable Wastes and Tariff

Tsung-Hsiu Tsai*

Department of Applied Economics, National University of Kaohsiung, Taiwan

Jiunn-Rong Chiou

Department of Economics, National Central University, Taiwan

2010/7/23

ABSTRACT

Inspiring by empirical works in the trade of recyclable wastes, we build a theoretical framework to examine the influence of recyclables import on domestic recycling business given that a recycling rate is mandated by the domestic government. We use paper market as an example and assume that original paper and recycled paper are perfect substitute. We ask what is the domestic government's decision-made on the tariff of imported original paper and how does domestic recycling rate affect on this tariff setting. It is found that, two factors: market size and the magnitude of environmental damage resulted from the production of recycled paper, have ambiguous effects on the optimal tariff setting. When the mandated recycling rate is sufficiently high, the domestic government may need to subsidize on the import of original paper.

Keywords: recycling rate, recyclable wastes, tariff, trade and the environment

* Corresponding author, Department of Applied Economics, National University of Kaohsiung, 700, Kaohsiung University Road, Kaohsiung 811, Taiwan. Email: thtsai@nuk.edu.tw Tel: 886-7-5919190. Fax: 886-7-5919319.

1. INTRODUCTION

In the recent decades, researchers have discovered a trend in the international trade of recyclable wastes: The volume of trade in recyclables has increased at least ten times since 1970s (Van Beukering, 2001). The flow of recyclable waste usually goes from developed countries to developing countries. In particular, China is the world's largest recyclable waste importer (Yoshida, 2005) and India and Indonesia are the main importers of used papers (Van Beykering, 2001a). It is generally believed that the increase of trade in recyclables is due to a strong demand in the domestic market. By importing recyclable wastes to produce recycled goods, the domestic market can reduce reliance on the import of original materials.

Although importing recyclable wastes sound beneficial, it is also evidently that the reclamation process of recycled goods may cause serious environmental damage in the domestic market. For example, the recovery industry of mixed metal scraps caused serious water pollution in Taiwan since the 1970s. Even now, the Environmental Protection Agency still has to spend a lot of money on cleaning this pollution. In China, two coastal provinces of Guangdone: Jiangsu and Zhejiang, suffer environmental damage from inappropriate disposal of e-waste (Yoshida, 2005). It is also confirmed that the crushing and washing process of PET bottles can yield 20 percent residues (Kojima, 2005). This is a byproduct that needs to be treated by importing countries.

Based on these observations, we are motivated to investigate the decision-made in the developing countries in the trade of recyclable wastes. As the import of recyclable wastes has both pros and cons, how to balance between gains of trade and environmental damage is an important task for the domestic government. Some kind of regulation is necessary. In this paper, we assume that the domestic government uses tariff as a regulatory instrument. As recycled goods producing from recyclable wastes are often substitute of original materials, we thus ask what is the optimal tariff level imposed on the import of original materials?[1]

Except examining the determinants of tariff on original goods, we are also interested in exploring the impact of recycling policy on this tariff setting. As more and more developing countries start to implement recycling programs, the tariff decision may need to take into account the performance of recycling activities. Current empirical evidences have shown us two phenomena: (1) Countries that are highly participated in trade of recyclable wastes tend to have higher recycling rates (Van Beukering and Bouman, 2001); and (2) domestic recycling performance reduces the import of original papers (Michael, 1998). As current literature provides no theoretical frameworks to explain these empirical observations, we figure that it is worth to examine the role of recycling in the trade of recyclable wastes.

Without loss of generality, we use the paper market as an example to illustrate our

[1] The domestic government is also capable to use the tariff of recyclable wastes as a regulatory instrument. However, in the reality, most countries have treated recyclable wastes as production inputs and thus levy negligible tariffs on them. For example, the tariff on waste paper in China is free. In Taiwan, the imported waste paper, copper scrap and aluminum scrap are all free. The tariff of waste plastics is 6.5% and iron scrap is only 0-3.8% (Kojima, 2005).

research agendas. We assume that (1) the imported original paper and domestic-made recycled paper are perfect substitute, and (2) the production process of recycled paper will cause environmental damage on the domestic environment. Given these two assumptions, we ask the determinants of optimal tariff on the foreign original paper and explore the influence of domestic mandated recycling rate on this optimal tariff.

We build a three-stage model to represent the interactions between the domestic government, a foreign firm that exports original paper, a foreign recycling firm that decides the paper scrap price, and a domestic firm that produces recycled paper.[2] We come out with several interesting findings. First of all, we find that the import of original paper does decreasing with recycling rate when certain condition is satisfied. This finding coincides with the empirical work discovered by Michael (1998). Secondly, we find that the optimal tariff of original paper is affected by many parameters. Most parameters have unambiguous impacts on the optimal tariff, expect for the market size and the marginal damage resulting from the production of recycled paper. Thirdly, we find that when domestic recycling rate is high and the market size is large enough, it is possible that the import of original paper should be subsidized, i.e. the optimal tariff can be negative. This last finding is interesting bceasue…

The rest of the paper is organized in the following way. Section 2 sets up the model.

[2] The domestic recycling market is assumed in a perfect competition. Due to free entry, the profit of each recycling firm is zero. For details, please see the description in section 2.

Section 3 analyzes the production behavior of the foreign original paper firm and domestic recycled paper firm. In Sections 4, we discuss the foreign recycling firm's decision on the price of paper scrap. Section 5 explores the domestic government's determination on the optimal tariff. Finally Section 6 concludes.

2. THE MODEL

There are two countries: H and F in our model. Country F (representing the developed countries) has abundant resources to produce original paper so that he has no need to produce recycled paper. There are two firms in country F. Firm *f* is responsible for producing original paper for both domestic use x and for export y. The marginal production cost of original paper is a constant c, with $c>0$. After use, the domestic original paper x becomes paper scrap and part of it will be collected and exported by firm *fr*. The paper collecting cost is assumed a constant ϕ with $\phi>0$. For each unit of original paper export y, firm *f* has to pay tariff t but firm *fr* does not have to pay tariff for paper scrap export. The export paper scrap is denoted by z with $z < x$; its price ω is determined by firm *fr*. To ensure a positive profit for firm *fr*, we assume $\omega > \phi$ holds.

It is assumed that country H (representing the developing countries) does not have resources to produce original paper. In order to satisfy domestic demand, country H can either import original paper or have her solely production firm *h* to produce recycled paper. Both original paper and recycled paper are assumed perfect substitute and are competing in country H with a Cournot fashion. Assume that the inverse demand function for paper market in Country H is $P=a-Q$ where $Q=y+q$ with y and q denoted as the imported original paper and domestic-made recycled paper. The marginal production cost for q is assumed a constant k, $k>0$.

The domestic firm h has two sources to purchase its inputs. One is to import z from country F. The other one is to purchase paper scrap from domestic recycling firms. The domestic recycling firms are in a perfect competition, free-entry market. Each recycling firm has a zero profit. Further assume that the government in county H mandates a recycling policy which can recycle β percent of paper scrap in the economy, $0 \le \beta < 1$. In every period, $\beta(y+q)$ amount of paper scrap will be collected by recycling firms with a constant marginal collecting cost γ. These domestic paper scrap will be sold to firm h with a unit price γ. It is mandated that firm h has to purchase all of the domestic paper scrap first. If it is not enough, the firm can then purchase foreign paper scrap z, with a unit price ω. This mandate implies that $\gamma < \omega$ must hold.

In this paper, we consider only the steady state. The output of recycled paper is indentified as $q = \lambda[z + \beta(y+q)]$, where z is the imported paper scrap, $\beta(y+q)$ is the domestic paper scrap and λ is a technology parameter that can transfer paper scrap into recycled paper. To simplify the model, we assume $\lambda=1$, which means that one paper scrap can make one unit of recycled paper.[3] The production of recycled paper has a by-product. Each unit of output production will cause a marginal damage *d* on the environment. For the amount of domestic paper scrap that is not collected and recycled $(1-\beta)(y+q)$, each of it will cause a marginal discharged damage *e* on the environment.

There are three stages in this model. In the first stage, the government in country H determines the optimal tariff on original paper. In the second stage, firm *fr* in country F decides the price of paper scrap ω. Finally, at the last stage, firms *f* and *h* are competing in country H. The backward induction method is applied to obtain this model's sub-game perfect equilibrium.

Table 1 summaries the notations used in this paper.

Table 1 List of Notations

	Country F (firm *f* and firm *fr*)	Country H (firm *h* and firm *hr*)
y	original paper output export	
z	paper scrap export	
q		recycled paper output
ω	price of paper scrap	
a		paper market size
c	marginal cost for the production of original paper	
k		marginal cost for the production of recycled paper
ϕ	paper scrap collecting cost	
γ		collecting cost for domestic paper scrap
d		marginal environmental damage caused from the production of recycled paper

[3] This steady state production function can be stated more clearly. Let us consider a two-period time frame. At period *t*-1, $\beta(y_{t-1}+q_{t-1})$ amount of domestic paper scrap will be collected and sold to firm *h*. At period *t*, in addition to $\beta(y_{t-1}+q_{t-1})$, the firm *h* imports foreign paper scrap z_t to produce *q*. Therefore, $q_t = z_t + \beta(y_{t-1}+q_{t-1})$. At the steady state, this production function becomes $q = z + \beta(y+q)$.

e		marginal environmental damage on discharged paper waste
β		recycling rate

3. THE OUTPUT COMPETITION

We look at both firms' output decisions first. Given on our model setting, firm *h*'s profit function can be written as next:

$$\begin{aligned} \underset{z}{Max} \quad & \pi^h = [a-(y+q)]q - \omega z - kq - r\beta(y+q) \\ s.t. \quad & q = z + \beta(y+q) \end{aligned} \tag{1}$$

The firm's profit function includes sale revenue, the purchasing cost for foreign paper scrap ωz, the total production cost kq, and the purchasing cost for domestic paper scrap $\gamma\beta(y+q)$. As illustrated, the constraint $q = z + \beta(y+q)$ defines the firm's output in the steady state. One can rewrite it as the following:

$$q = \frac{z}{1-\beta} + \frac{\beta y}{1-\beta}. \tag{2}$$

As the output of firm *h* is also affected by its rival's output, it can only decide the amount of paper scrap purchase *z* but not to decide output *q* directly.

The first-order condition $\partial\pi^h / \partial z = 0$ indicates that the firm's reaction function is:

$$(1+\beta)y + 2z = (1-\beta)[a-(1-\beta)\omega - \beta\gamma - k]. \tag{3}$$

Next, we show the firm *f*'s profit function as next:

$$\underset{x,y}{Max} \ \pi^f = (b-x)x + [a-(y+q)]y - ty - c(x+y). \tag{4}$$

The firm *f*'s profit includes the sale revenues from both domestic and foreign markets, the total tariff paid to country H *ty*, and total production cost *c*(*x*+*y*).[4]

After some arrangements from the first-order condition $\partial \pi^f / \partial y = 0$, we get the firm's reaction function as next:

$$2y + z = (1-\beta)[a - c - t]. \tag{5}$$

Solving equations (3) and (5) simultaneously, we can obtain *y* and *z* as the following[5]:

$$y = \frac{1-\beta}{3-\beta}[a - 2\ c + (t) + \omega - \beta(\omega - \gamma) + k)]. \tag{6}$$

$$z = \frac{1-\beta}{3-\beta}[(1-\beta)a + (1+\beta)(c+t) - 2\omega + 2\beta(\omega - \gamma) - 2k]. \tag{7}$$

To ensure positive *y* and *z*, we assume the market size *a* is large enough.

A simple static equilibrium analysis shows the impacts of *t* and ω on *y* and *z* in the following:

$$\frac{\partial y}{\partial \omega} = \frac{(1-\beta)^2}{3-\beta} > 0, \quad \frac{\partial y}{\partial t} = -\frac{2(1-\beta)}{3-\beta} < 0,$$
$$\frac{\partial z}{\partial \omega} = -\frac{2(1-\beta)^2}{3-\beta} < 0, \quad \frac{\partial z}{\partial t} = \frac{(1-\beta^2)}{3-\beta} > 0. \tag{8}$$

As one can see the increase of foreign paper scrap price increases firm *f*'s export and lowers firm *h*'s import for paper scrap. This is because the increase of scrap price increases its rival's cost burden, firm *f* thus gains a better competition in the market and thus can export more to country H. The impact of tariff has an oppose effect on both firms. When tariff increases, the domestic (foreign) firm has a better (less) competition place in the market.

[4] As one can easily tell, the firm's decision on output *x* is not important in this paper. Our focus is on *y*. The purpose for us to write the firm's profit function as (4) is to emphasize that the constraint *z*<*x* holds as illustrated in section 2.

[5] The second-order conditions are both satisfied $\pi^H_{zz} = -2/(1-\beta)^2 < 0$ and $\pi^F_{yy} = -2/(1-\beta) < 0$.

More production implies higher derived demand for inputs. Therefore, z increases with tariff.

Furthermore, the impacts of recycling rate β on y and z are as follows:

$$\frac{\partial y}{\partial \beta} < 0, \quad \frac{\partial z}{\partial \beta} < 0. \tag{9}$$

Proposition 1*: Given the levels of tariff and foreign paper scrap price, both original paper output and paper scrap import decreases with the recycling rate.*

The intuition of Proposition 1 is as follows. The increase of recycling rate has two impacts on y. First of all, the increase of β increases domestic recycled paper output q due to $q = (z + \beta y)/(1-\beta)$. Secondly, the increase of β saves the input cost burden for firm h; and this increases q as well. As both forces stimulate the production of recycled paper, the original paper import thus decreases.

On the other hand, there are three forces that determine the impact of recycling rate on foreign paper scrap purchase. First of all, from (2) we know the increase of β decreases the derived demand for foreign paper scrap due to $z = q - \beta(y+q)$. Secondly, the increase of β reduces y and this is the force mentioned in the above paragraph. Based on (2), lower y implies lower level of q due to $q = (z + \beta y)/(1-\beta)$. Lower level of q implies less derived demand for z. Thirdly, the increase of β will save the input cost burden $(\omega - \gamma)$. This cost-reducing effect will cause the firm h to increase its output q and thus demand more z. Although the last force asks for more z when β increases, the first two forces are stronger than the last one. Overall, the impact of recycling rate on foreign paper scrap import is negative.

4. THE OPTIMAL PAPER SCRAP PRICE

Next, we move to the second stage to examine the decision of firm *fr* on the optimal paper scrap price ω. The firm's profit function can be written as next:

$$\underset{\omega}{Max} \quad \pi^{fr} = z(\omega)\cdot(\omega-\phi) \tag{10}$$

Substituting (6) and (7) into the first-order condition $\partial\pi^{fr}/\partial\omega = z + (w-\phi)\cdot\partial z/\partial\omega = 0$, one can obtain the optimal scrap price as next:

$$\omega^* = \frac{1}{4(1-\beta)}[(1-\beta)a + (1+\beta)(c+t) - 2(\beta\gamma + k) + 2(1-\beta)\phi] \tag{11}$$

As one can see the impact of tariff *t* on ω^* is positive, i.e. $\frac{d\omega^*}{dt} > 0$. This is because the increase of tariff reduces the original paper output and increase the recycled paper output *q*. As the increase of recycled paper requires more input *z*, the foreign country thus can rise the paper scrap price ω.

We can also examine the influence of β on the foreign paper scrap price ω as next:

$$\frac{d\omega^*}{d\beta} = \frac{1}{2(1-\beta)^2}[(c+t)-(\gamma+k)] \tag{12}$$

The sign of $d\omega/d\beta$ is dependent on the relative magnitudes of (c+t) and (γ+k). When $(c+t) > (\gamma+k)$, $d\omega/d\beta > 0$. We know that when its rival's production cost *c* and tariff *t* imposed is relatively high, the firm *h*'s output of recycled paper will increase and its derived demand for *z* will also be higher. Firm *fr* thus can increase the paper scrap price ω. Suppose now the recycling rate increases. Firm *h* can obtain more input and can produce even more output, and its demand for foreign paper scrap is stronger than before. This pushes a higher foreign paper scrap price. Therefore, the increase of recycling rate exaggerates the impact of *c* and *t* on ω, $d\omega/d\beta > 0$.

Alternatively, it is also possible that $(c+t) < (\gamma + k)$ holds. Facing a relatively high domestic paper scrap price γ and production cost *k*, firm *h* will reduce its output of recycled paper. This decreases the derived demand for *z* and therefore lowers the foreign paper scrap price. Although the increase of recycling rate can stimulate the firm to produce more output, this force is discounted by high γ and *k*. Overall, $d\omega/d\beta < 0$

Proposition 2: *When* $c+t > \gamma + k$ *holds (* $c+t < \gamma + k$ *), the increase of recycling rate increases (decreases) the foreign paper scrap price.*

Substituting ω^* into equations (5) and (6), we can rewrite *y* and *z* as next:

$$y^* = \frac{1-\beta}{4(3-\beta)}[(5-\beta)a - (7-\beta)(c+t) + 2(\beta\gamma + k) + 2(1-\beta)\phi] \tag{13}$$

$$z^* = \frac{1-\beta}{2(3-\beta)}[(1-\beta)a + (1+\beta)(c+t) - 2(\beta\gamma + k) - 2(1-\beta)\phi] \tag{14}$$

As $\frac{d\omega^*}{d\beta}$ may be positive or negative, the impact of recycling rate on y^* and z^* thus has two possibilities.

Case (1) $c+t > \gamma + k$, $\frac{d\omega^*}{d\beta} > 0$

Recall that from (8), we know $\frac{\partial y}{\partial \beta} < 0$ and $\frac{\partial y}{\partial \omega} > 0$, therefore the sign of $\frac{dy^*}{d\beta} = \frac{\partial y}{\partial \beta} + \frac{\partial y}{\partial \omega}\frac{d\omega}{d\beta}$ is thus ambiguous. Also recall that $\frac{\partial z}{\partial \beta} < 0$ and $\frac{\partial z}{\partial \omega} < 0$, the sign of $\frac{dz^*}{d\beta} = \frac{\partial z}{\partial \beta} + \frac{\partial z}{\partial \omega}\frac{d\omega}{d\beta}$ is thus negative.

Case (2) $c+t<\gamma+k$, $\dfrac{d\omega^*}{d\beta}<0$

As $\dfrac{\partial y}{\partial \beta}<0$ and $\dfrac{\partial y}{\partial \omega}>0$, the sign of $\dfrac{dy^*}{d\beta}=\dfrac{\partial y}{\partial \beta}+\dfrac{\partial y}{\partial \omega}\dfrac{d\omega}{d\beta}$ is thus negative.

As $\dfrac{\partial z}{\partial \beta}<0$ and $\dfrac{\partial z}{\partial \omega}<0$, the sign of $\dfrac{dz^*}{d\beta}=\dfrac{\partial z}{\partial \beta}+\dfrac{\partial z}{\partial \omega}\dfrac{d\omega}{d\beta}$ is hence ambiguous.

Proposition 3*: When $c+t>\gamma+k$ holds, the increase of recycling rate reduces the import of foreign paper scrap z. Alternatively, when $c+t<\gamma+k$ holds, then the increase of recycling rate reduces the import of original paper y.*

Recall that in section 1 we mentioned that empirical works have discovered that countries participate more in the trade of recyclable waste also has a higher recycling rate (Van Beukering and Bouman, 2001), and domestic recycling program can reduce the import of original paper (Michael, 1998). Based on Proposition 3, our theoretical finding supports the work of Michael (1998) when the condition $c+t<\gamma+k$ is satisfied. We however cannot tell the first finding proposed by Van Beukering and Bouman (2001). In their statement, the relationship between z and β is positive. In our model, we discover that the impact of β on z is negative. We are unable to tell the influence of z on β.

5. THE OPTIMAL TARIFF

We now move to the first stage to analyze the government's decision on the optimal tariff of original paper. The government's social welfare maximization problem in country H can be written as next:

$$\underset{t}{Max} \quad W^H = \frac{(y^* + q^*)^2}{2} + \pi^h + ty^* - dq^* - e(1-\beta)(y^* + q^*) \tag{15}$$

This social welfare function contains the consumer surplus, the profit of firm h, tariff revenue, negative environmental damage caused by the production of recycled paper dq, and the negative environmental damage from the discharged waste $e(1\text{-}\beta)(y\text{+}q)$.

Substituting (13) and (14) into (15), the optimal tariff, denoted as t^*, can be calculated as as represented next:

$$t^* = \frac{1}{A}\begin{Bmatrix} (33 - 70\beta + 35\beta^2 - 6\beta^3)a + (-51 + 12\beta + \beta^2 + 2\beta^3)c \\ + 2(9 + 29\beta - 18\beta^2 + 2\beta^3)k + 2(1-\beta)(9 - 13\beta + 2\beta^2)\phi \\ + 2\beta(51 - 33\beta + 4\beta^2)\gamma - 4(3-\beta)(2 - 5\beta + \beta^2)d \\ + 4(3-\beta)(1-\beta)(5-3\beta) \end{Bmatrix} \tag{16}$$

where $A = 135 - 136\beta + 43\beta^2 - 6\beta^3 > 0$. As one can see, the determinant of the optimal tariff is complicated. We however can observe the impacts of parameters on the optimal tariff.

Proposition 4: *Except for the production cost of original paper (c) has a negative impact on t^*, most parameters such as the production cost of recycled paper (k), the domestic paper scrap price (γ), the foreign paper scrap collecting cost (φ), and environmental damage from discharged waste (e) all have positive impacts on the optimal tariff.*

The explanation of proposition 4 is as follows.

(1) The production cost of original paper c affects t^* negatively. This is because a higher level of production cost c will result a lower level of original paper output y and thereby the profit of firm f is at a lower level. As the government in country H can deprive less

rent from the foreign firm, the optimal tariff thus can be set lower.

(2) The production cost of recycled paper k and domestic paper scrap price γ both affect t^* positively. A higher level of k and γ implies that the domestic firm h has a higher production cost and thus a lower output level. The foreign firm thereby can export more original paper to country H. In order to deprive rent from the foreign firm, the government can set a higher level of tariff.

(3) The foreign paper scrap collecting cost φ has a positive impact on t^*. A high level of scrap collecting cost implies a high foreign paper scrap price, and the firm h has to pay more on foreign input purchase. This increases the competitiveness of firm f in the market. The government thus wants to impose a higher tariff on y.

(4) The environmental damage from discharged waste e has a positive impact on t^*. When e is high, the government may want to reduce both q and y. The tariff thus can be set higher.

Note that in Proposition 4, we exclude the influences of market size a and environmental damage from recycled paper production d on the optimal tariff. This is because these two parameters have ambiguous influences on t^* and their impacts on t^* depends on the recycling rate. To demonstrate our argument, we calculate the optimal tariff level when there is no recycling mandate as the following:

$$t^* |_{\beta=0} = \frac{1}{135}\{33a - 51c + 18\phi + 18k - 24d + 60e\} \qquad (17)$$

As one can see, when the recycling rate approaches to zero, the impact of parameter *d* on t^* is negative. This is because the production of recycled paper will reduce the domestic social welfare. To avoid such damage from production, it is better to import original paper. In this sense, the government may want to set a lower tariff to encourage more foreign output import. However, when the recycling rate increases, $\beta \to 1$, the low tariff may attract too many original paper import. As the production of recycled paper will be stimulated by *y* through recycling due to $q = (z + \beta y)/(1 - \beta)$. The increase of recycled paper production generates cause too much environmental damage. In this sense, the government may want to rise the tariff in order to protect the environment. Therefore, when recycling rate is high, the impact of environmental damage from production on t^* is positive.

Now, let us look at the impact of parameter *a* on t^*. When $\beta \to 0$, this impact is positive. This result is not too surprising. When the recycling rate is negligible, the production of recycled paper has to rely more on the import of paper scrap. In order to deprive more rent from the foreign firm, the optimal tariff thus can be set higher. However, when $\beta \to 1$, the impact of *a* on t^* is reversed. We know that the production of *q* is contributed partially from y, i.e. $q = (z + \beta y)/(1 - \beta)$. Higher recycling rate can exaggerate the impact of *y* on *q*. If imposing a high tariff on *y*, then the domestic production *q* will be affected adversely. The impact of *y* on *q* through recycling will even be stronger when the market size is large. The reduction of *y* affects not just the consumer surplus but also the profit of the domestic firm *h*. Therefore, when the recycling rate is high enough and market size is large, the impact of *a* on t^* may be negative. We summarize this result in the following.

Proposition 5: If the mandated recycling rate is very high, then a very large market size may result a subsidy on original paper import, ceteris paribus.

6. CONCLUSION

Inspiring by empirical works, we are motivated to explore the influence of domestic recycling rate on the imports of original paper and recyclable wastes through a theoretical framework. We ask two specific questions in this paper: What is the social optimal tariff for imported original paper and how does domestic recycling policy affect on the tariff setting. This theoretical deduction provides some interesting insights which cannot be observed from empirical findings.

Our first finding is that the optimal tariff of original paper depends on many parameters. Except for the foreign firm's production cost which has a negative impact on the optimal tariff, most parameters such as the production cost of recycled paper, the foreign paper scrap collecting cost, the domestic paper scrap price, and the environmental damage from discharged waste all have positive impacts on the optimal tariff. The intuition of these results has been elaborated in section 5.

Our second finding shows that the impacts of market size and environmental damage from the production of recycled paper on the optimal tariff are ambiguous. They are affected by the recycling rate. Without any recycling rate mandate, the government should set up a higher (lower) tariff when the paper market size is large (the environmental damage from production is low). However, when the recycling rate mandate increases, it is possible that the import of original paper should be subsidized rather than taxing, especially when market size is large. The main reason for this result is because the domestic recycled paper production relies partially on foreign original paper. If imposing a high tariff on foreign original paper, the market may result too few output and the domestic firm's profit will be affected adversely as well. This finding basically tell us that if a country has a recycling rate mandate, then the government may need to reduce the tariff imposed on original materials when domestic market is large. In some extreme, the government may need to subsidize on original material import in order to make sure that the domestic recycling material production has sufficient amount of inputs.

Finally, we find that when certain condition is satisfied, the increase of recycling rate can reduce the reliance on foreign original paper import. In the oppose condition, the increase of recycling rate can reduce the import of foreign paper scrap. This theoretical finding partially matches with the empirical finding. We however cannot find the evidence that the increase of recycling rate pushes up the import of recyclable wastes.

For future research, we suggest one direction. In this paper, we assume that the domestic government has mandated a recycling rate and uses tariff as a regulatory instrument to balance between trade and the environment. One might try to use the domestic recycling rate as a policy instrument. As trade liberalization has become a trend, the setting of recycling rate may be worth to explore.

References:

Cassing James and T. Kuhn (2003), Strategic environmental policies when waste products are tradable, *Review of International Economics*, 11(3), 495-511.

Copeland, Brian (1989), International trade in waste products in the presence of illegal disposal, *Journal of Environmental Economics and Management*, 20, 143-62.

Duraiappah et. al. (2002), Issues in production, recycling and international trade: analyzing the Chinese plastic sector using an optimal life cycle (OLC) model, *Environment and Development Economics*, 7, 47-74.

Kojima Michikazu (2005), Current trade flows in recyclable resources within Asia & related issues, Chapter 1 in *International Trade of Recyclable Resources in Asia* (edited by Kojima Michikazu), Institute of Developing Economies, Japan.

Michael Jeffrey (1998), Recycling, international trade, and the distribution of pollution: the effect of increased U.S. paper recycling on U.S. import demand for Canadian paper, Journal of Agricultural and Applied Economics, 30:1, 21/-223.

Van Beukering, Pieter and M. Bouman (2001), Empirical evidence on recycling and trade of paper and lead in developed and developing countries, *World Development*, 29(10), 1717-1737.

Van Beukering, Pieter J.H. (2001), *Recycling, International Trade and the Environment: An Empirical Analysis*, Kluwer Academic Publishers.

Yoshida Aya (2005), China: the world’s largest recyclable waste importer, Chapter 3 in *International Trade of Recyclable Resources in Asia* (edited by Kojima Michikazu), Institute of Developing Economies, Japan.

Global Reuse and Optimal Waste Policy

Hide-Fumi Yokoo

National Institute for Environmental Studies
16-2 Onogawa,
Tsukuba,
Ibaraki 305-8506, Japan
yokoo.hidefumi@nies.go.jp
+81 29 850 2952

and

Thomas C. Kinnaman

Department of Economics
Bucknell University
Lewisburg, PA 17837, USA
kinnaman@bucknell.edu
(570) 577-3465

May 18, 2010

The authors wish to thank Ken-Ichi Akao, Satoshi Honma, Naoto Jinji, Yuichi Moriguchi, Takayoshi Shinkuma, and Kazuhiro Ueta for helpful comments on earlier drafts.

Abstract

This paper develops a two-country model to solve for optimal tax policies necessary to achieve the efficient level of economic resources in an economy with global reuse. In the baseline case both the developed and developing economies are able to initiate tax policies to internalize the social costs of waste disposal. Unsurprisingly, optimal policy requires each disposal tax be equal to the external marginal cost in each country. The model is then extended to the more interesting case where only the developed nation can tax waste. The global Pareto Optimum can still be obtained by either taxing the importation of the used durable good or subsidizing consumer return of durable waste for eventual disposal back in the developed country. If no policy instruments are available in the developing country, the global Pareto Optimum is obtained by reducing the disposal tax in the developed country to a level below their external marginal cost of disposal.

Keywords: Solid waste, taxation, durable goods

1. Introduction

Advances in communication technologies coupled with reductions in transportation costs have increased the scope of global trade over the past 100 years. Recently global trade has included the export of used durable goods from developed to less developed economies. For example, about 10.2 million used computers – roughly 80% of all used computers collected from firms and households in the United States - were exported to Asia in 2002 (Puckett and Smith, 2002). Roughly one-fourth of all used computers collected for firms and households in Japan were exported to developing nations in 2004 – up from just 8% in 2000 (Yoshida et al., 2009). About 2.5 million used cars and trucks were exported from the United States to Mexico between 2005 and 2008 (Davis and Kahn, 2008).

Exporting used durable goods to developing economies for further consumption, a concept we call "global reuse", provides utility to consumers in developing countries but can have negative social consequences if the resulting waste contains toxic substances. The cathode ray tubes of televisions and personal computers, for example, contain large amounts of lead oxide and cadmium – substances harmful to the natural environment and human health. The circuit boards of computers and cell phones also contain lead and cadmium. Modern flat-screen panel monitors contain mercury, another harmful pollutant potentially damaging to human organs.[1]

Thus the waste from these durable goods can be hazardous, and advanced

---

[1] Inorganic mercury mixed with water is transformed to methylated mercury. Methylated mercury easily accumulates in living organisms and concentrates through the food chain. Cadmium compounds accumulate in the human body, particularly the kidneys, and have irreversible consequences for human health, (Puckett and Smith, 2002). From the study of Yoshida (2002), each cathrode ray tube contains about 2kg of lead, enough to damage human central and peripheral nerves, which can have a deleterious effect on the growth and development of children. Lead is also an endocrine disruptor.

disposal techniques can be necessary to mitigate external effects of disposal. Such disposal technologies are often available in developed countries. But less developed importing countries such as China, Philipine, India, Pakistan, Mexico or Nigeria rarely possess the technologies, policies, and enforcement infrastructures necessary to control external disposal costs. In Guiyu, China, for example, broken CRTs are regularly dumped on open land or pushed into rivers (Puckett and Smith, 2002). In Nigeria, used televisions and computers are used to fill swamps (Puckett, 2005).

This paper develops a two-country model to solve for optimal taxes and subsidies necessary for allocative efficiency in an economy with global reuse. The model, we believe, is easy to understand and replicate. Results are intuitive and relevant to policy formation. In the baseline case, developed in Section 3 of this paper, both the developed and developing economies are able to initiate tax policies to internalize the social costs of waste disposal. Unsurprisingly, optimal policy requires each disposal tax be equal to the external marginal cost within each country. The model is then extended in Section 4 to the more interesting case where only the developed nation can tax waste. Under this assumption, and when coupled with a disposal tax in the developed country, the government of the developing country can still achieve the global Pareto Optimum by either taxing the importation of the used durable good or subsidizing consumer return of durable waste for eventual disposal back in the developed country. The model in Section 5 considers the case when policy instruments are unavailable to the developing country. The global Pareto Optimum is obtained by reducing the disposal tax in the developed country to a level below their external marginal cost of disposal. Before introducing the model, the next section of this paper summarizes the literature on durable goods and the international market for waste.

2. The Literature

In a closed economy, several papers have demonstrated that the optimal policy for internalizing the social costs of waste disposal is a tax on disposal set equal to the external marginal cost of disposal (beginning with Wertz, 1976). Where illegal dumping is problematic, the disposal tax is replaced by a subsidy to recycling coupled with a tax on consumption – a deposit refund program (Fullerton and Kinnaman, 1995). Shinkuma (2007) extends the waste policy literature for a closed-economy to the case of durable goods by demonstrating that advanced disposal fees lead to inefficient choices between reuse and disposal.

The solid waste literature on open economies focuses almost entirely on the international transfer of pure waste, rather than on goods embedded with waste. Copeland (1991) argues that eliminating trans-national shipments of waste can improve welfare if importing governments do not adequately regulate waste disposal or if such regulations cause illegal dumping in those countries. For the case of durable goods, banning international trade may not be efficient if the additional value consumers place on imported used durable goods exceeds the difference in external costs of disposal between the importing and exporting country. Rauscher (2001) examines international trade in hazardous waste.

A collection of other papers examines the strategic use of waste taxes to alter trade patterns. For example, Krutilla (1991) suggests national governments will set waste taxes in exporting industries to levels above the external cost of disposal to reduce supply and therefore improve international terms of trade. Waste taxes in importing industries, on the other hand, are set below external costs to help these industries compete globally. Alternatively, Kennedy (1994) argues that where competition is imperfect, governments could (1) reduce domestic disposal taxes to improve rents to exporting industries while at the same time (2) increase domestic disposal taxes to encourage the transfer of waste to other countries. The first effect is found to outweigh the second effect if the external costs of waste disposal do not extend beyond a nation's borders. Cassing and Kuhn (2003) find that importing countries levy waste taxes below the external marginal cost of disposal and below waste taxes in exporting countries to correct for the market inefficiency caused by imperfect competition in exporting countries. Barrett (1994) and Simpson (1995) also examine the use of environmental waste taxes as substitutes for trade taxes. Although we do not model strategic trade behavior, the paper contributes to this literature by considering the substitutability of waste and trade taxes for reaching global efficiency.

Research into closed economies with durable goods goes back at least as far as Anderson and Ginsburgh (1994). More recently, Thomas (2003) focuses on the relationship between material consumption and transaction costs of second-hand markets and Yokoo (2010) examines the impact of reuse activity on consumer welfare. Shinkuma (2009) is the first to distinguish durable goods from non-durable goods in the context of optimal waste policy in a global setting and finds that an advanced disposal fee is globally inefficient. Our study expands upon the work of Shinkuma (2009) by considering policy options beyond a producer responsibility measure.

3. Waste Taxes Available to Both Countries ($t^A_w>0$, $t^B_w>0$)

This section develops a baseline model where both a developed and developing country can tax waste. This model expands upon a domestic waste model of Fullerton and Kinnaman (1995), Fullerton and Wu (1998), and Kinnaman (2010). The model does not attempt to explain *why* one country is more economically developed than the other, but assumes incomes and production technologies in each country are determined exogenously.

Assume an open economy is comprised of two countries. Country A is endowed with a technology to produce durable goods such as televisions, computers, or automobiles. The durable good is initially consumed only in Country A, as Country B is assumed to not possess the technology to produce the durable good, nor do consumers have incomes sufficient to import new durable goods from Country A. Instead the consumers of Country B import used durable goods from Country A.

After consuming the durable good (with quantity d), consumers in Country A either dispose the good as waste in Country A (w^A) or export the good to Country B for reuse (e). Thus $d = w^A + e$ (where $w^A, e \geq 0$). Once the used durable good has been consumed in Country B, it becomes waste to be disposed in Country B (w^B), thus $e = w^B$. Assume all of this consumption and disposal activity occurs within a single time period. Within the context of a dynamic model, the conditions $d = e + w^A$ and $e = w^B$ could describe a steady state.[2]

Assume country A is comprised of n identical consumers each with utility (U^A) defined over their own consumption of the durable good (d) and the total quantity of waste disposed in Country A (nw^A),

(1) $$U^A = U^A(d, nw^A), \quad \text{where } U_d > 0 \text{ and } U_w < 0.$$

Assume a global economic resource such as capital or energy (k) constitutes the

[2] See Yokoo (2010) for theoretical treatment of durable good consumption in a dynamic model.

only input into several production processes. First, the economic resource (with quantity k^d) can be employed to produce the durable good (d) in Country A according to the production function,

(2) $$d = f(k^d), \text{ where } f' > 0.$$

Second, the economic resource (k^w) can be used to collect and dispose the used durable good as waste in Country A (w^A) according to the production function

(3) $$w^A = g(k^w), \text{ where } g' > 0.$$

Third, transporting the used durable good from Country A to Country B requires the economic resource (k^e) according to $e = e(k^e)$. This function can be inverted to solve for k^e,

(4) $$k^e = k^e(e), \text{ where } k^{e\prime}>0.$$

In Country B, the representative consumer gains utility (U^B) from consuming the imported used durable good (e), consuming a non-durable good (c), and the aggregate quantity of waste resulting from used durable goods (mw^B, where m denotes the number of identical consumers in Country B and recall that $e = w^B$)

(5) $$U^B = U^B(e, c, mw^B), \text{ where } U^B{}_e > 0, U^B{}_c > 0, \text{ and } U^B{}_w < 0.$$

The non-durable good (c) is produced in Country B using the same global economic resource available to Country A above (with quantity k^c, the fourth use of the resource) according to the production function,

(6) $$c = h(k^c), \text{ where } h'>0.$$

Assume this non-durable good does not generate waste sufficient to affect the utility of the consumers of Country B. Examples of such a good could include agricultural products, local services, or leisure.

Waste resulting from the used durable good consumed in Country B is processed and disposed using the economic resource (k^b) according to,

(7) $w^B = b(k^b)$, where $b'>0$.

Finally, assume the total quantity of the global economic resource available to the five production processes is $\bar{k}$ and is fully employed,

(8) $\bar{k} = k^d + k^w + k^e + k^c + k^b$.

Social Efficiency

To achieve the Pareto Optimal allocation of the economic resource across the five production processes, a social planner maximizes the utility of the representative consumer in Country A subject to holding the utility of the representative consumer in Country B constant at $\bar{U}^B$. The social planner is constrained by the materials balance conditions ($d = e + w$ and $e = w^B$), the five production functions (in 2, 3, 4, 6, and 7), and the resource constraint given in (8). Upon substitution, the problem reduces to choosing k^w, k^b, and k^d to maximize the Lagrange function,

$$\mathcal{L} = U^A\{g(k^w)+b(k^b), ng(k^w)\}$$
$$+ \lambda_1[\bar{U}^B - U^B\{h[\bar{k} - k^d - k^w - k^e(b(k^b)) - k^b], b(k^b), mb(k^b)\}]$$
$$+ \lambda_2[f(k^d) - g(k^w) - b(k^b)]$$

where λ_1 and λ_2 are Lagrange multipliers. The latter represents the marginal utility of producing an additional unit of the durable good. The first-order conditions are

(9a) $\mathcal{L}_{kw}$: $U^A_d g' + nU^A_w g' = \lambda_1[-U^B_c h'] + \lambda_2[g']$

(9b) $\mathcal{L}_{kb}$: $U^A_d b' = \lambda_1[-U^B_c h' k^{e\prime} b' - U^B_c h' + U^B_e b' + mU^B_w b'] + \lambda_2[b']$

(9c) $\mathcal{L}_{kd}$: $\lambda_2[f'] = \lambda_1[-U^B_c h']$

Divide (9a) through by g', divide (9b) through by b', and solve (9c) for λ_1 and substitute into (9a) and (9b) to eliminate λ_1. We are left with, (10a) $U^A_d/\lambda_2 = f'/g' + 1 - nU^A_w/\lambda_2$

(10b) $U^A_d/\lambda_2 = f'k^{e'} + f'/b' - U^B_e f'/U^B_c h' - mU^B_w f'/U^B_c h' + 1$

These two equations summarize the Pareto Optimal allocation of the economic resources across the five uses in the economy. These conditions will be compared to those of the competitive equilibrium in the next section to determine optimal tax rates.

Competitive Equilibrium

Assume a disposal tax is available to the governments of both countries (t^A_w and t^B_w). Assume a representative consumer in Country A faces prices $p_d = 1$ (the numeraire) to purchase the durable good, p^A_w to dispose the resulting waste from the durable good in Country A, and receives p_e for each unit of the used durable good exported to Country B. Assume the consumer must also pay p_k for the economic resource necessary to employ the technology in (4) to prepare and transport the used durable good to Country B.[3] These prices give rise to the consumer's budget constraint,

$$M^A = d + p^A_w w_A + p_k k^e(e) - p_e e,$$

where M_A denotes an exogenously determined level of consumer income. The representative consumer maximizes utility (1) subject to the above budget constraint and the materials balance constraint $d = w^A + e$. Because the number of consumers is large (n), the representative consumer considers its own contribution to the overall waste externality to be zero. The aggregate quantity of waste (nw^A) is therefore

[3] The assumption that consumers employ the technology in (4) to export the used durable good is made purely out of convenience. An export firm could be added to the model that employs the same technology and charges a price to the consumer for this service. Optimal taxes defined below would not change.

exogenous to the representative consumer. The consumer chooses w^A and e to maximize the Lagrange function,

$$\mathcal{L} = U^A(w^A + e, \overline{nw}^A) + \partial^A[M^A - (w^A + e) - p^A{}_w w^A - p_k k^e(e) + p_e e]$$

where ∂^A, the Lagrange multiplier, denotes the marginal utility of income. The first-order conditions are

(11a) $\mathcal{L}_{wA}$: $U^A{}_d = \partial^A[1+ p^A{}_w]$

(11b) $\mathcal{L}_e$: $U^A{}_d = \partial^A[1 + p_k k^{e\prime} - p_e]$.

The representative consumer purchases the durable good to the point that the marginal utility of consumption is equal to the price of durable good plus the overall cost of each of the two disposal options. The utility-maximizing consumer will choose between domestic disposal and export for global reuse such that $p^A{}_w = p_k k^{e\prime} - p_e$.

Assume a representative competitive firm utilizes the production technology defined in (2) to produce the durable good. This firm chooses the quantity of the economic resource to employ (k^d) to maximize profit

$$\pi = f(k^d) - p_k k^d.$$

Profit is maximized when

(12) $f' = p_k$

Assume a representative competitive firm collects and disposes waste in Country A by employing the economic resource (k^w) and the technology given in (3). This firm also pays a tax of $t^A{}_w$ on each unit of waste disposed. The firm chooses the quantity of the economic resource (k^w) to maximize profit

$$\pi = (p^A{}_w - t^A{}_w)g(k^w) - p_k k^w.$$

Profit is maximized when

(13) $p^A{}_w = p_k/g' + t^A{}_w$.

The representative consumer in Country B maximizes utility (5) subject to $e = w^B$ (all imported used durable goods are disposed in Country B) and the budget constraint

$$M^B = p_e e + p_c c + p^B_w w^B,$$

where p_c is price of the non-durable good and once again p_e is the price of the used durable good imported from Country A. The consumer also pays a price of p^B_w to dispose the waste from the durable good. Because the number of consumers in Country B is large (at m), the representative consumer considers the aggregate quantity of used durable goods disposed in Country B (mw^B) to be exogenous. The Lagrange function for this constrained utility-maximization problem is

$$\mathcal{L} = U^B(w^B, c, \overline{mw}^B) + \delta^B[M^B - p_e w^B - p_c c - p^B_w w^B].$$

The first-order conditions for utility maximization are

$$\mathcal{L}_{wb}: \quad U^B_e = \delta^B[p_e + p^B_w]$$

(14) $$\mathcal{L}_c: \quad U^B_c = \delta^B[p_c],$$

which can be simplified to the single condition

(15) $$U^B_e/U^B_c = (p_e + p^B_w)/p_c.$$

The competitive firm in country B uses the technology in (6) to produce the non-durable good to maximize profit $\pi = p_c h(k^c) - p_k k^c$ by choosing k^c such that

(16) $$p_c = p_k/h'.$$

Finally a competitive firm in Country B employs the disposal technology in (7) to dispose waste from the durable good in Country. In this baseline case the government of Country B can tax this waste to encourage waste producers to internalize the social costs of disposal. Profit $\pi = (p^B_w - t^B_w)b(k^b) - p_k k^b$ is maximized when

(17) $$p^B_w = p_k/b' + t^B_w.$$

Substitute (16), (17), and (12) into (15) to eliminate p_c, p^B_w, and p_k. Solve the resulting equation for p_e and substitute into (11b) to eliminate p_e. Then substitute (13) into (11a) to eliminate p^A_w and substitute (12) into (11a) and (11b) to eliminate p_k. We are left with

(18a) $U^A_d/\partial^A = 1 + f'/g' + t^A_w$

(18b) $U^A_d/\partial^A = 1 + f'k^e - U^B_e f'/U^B_c h' + f'/b' + t^B_w$

These equations summarize the allocation of resources in a decentralized economy as a function of the two waste taxes. Compare (18) with (10) and note that the Pareto Optimum can be achieved by the competitive equilibrium when tax rates are set as follows

$t^A_w = - nU^A_w/\lambda_2$ and $t^B_w = - U^B_w f'/U^B_c h'$

Combining (14), (16), and (12) suggests $f' = U^B_c h'/\delta^B$ allowing the optimal tax rates to be simplified to

$t^A_w = - nU^A_w/\lambda_2$ and $t^B_w = - mU^B_w/\delta^B$

Controlling for a few changes in notations and a few other features of the model, this result is similar to Fullerton and Kinnaman (1995), who solve for the optimal tax in a closed economy. A country sets a tax rate on waste disposal equal to the external marginal cost of waste disposal (nU^A_w and U^B_w, respectively). The Lagrange multipliers convert the units of taxation from utiles to dollars.

Notice that the optimal waste tax does not depend upon the durable nature of the exported good. If consumers in Country B gain no utility from the imported material ($U^B_e = 0$), the optimal tax policy remains the same. Thus, it makes little difference to formation of optimal policy whether computers and televisions are being exported as pure waste products or as used goods with additional consumptive value.

That the international transfer of waste is treated differently by the policy community than the international transfer of goods embedded with waste is beyond the explanatory scope of the model.

4. Waste not Taxed in Country B *(t^B_w=0)*

Consider the same economy as described above with the added assumption that the government of Country B is unable to tax waste disposal. Perhaps the economy lacks the necessary technology (scales for weighing trucks entering and exiting landfills, for example) or the government lacks the resources to discourage illegal dumping that might arise with the implementation of a waste tax (Copeland, 1991). This section explores alternative tax instruments available to government of Country B for achieving the Pareto Optimal allocation of the economic resource when waste is untaxed. The first is a tax on imports of the used durable good. The second is a subsidy paid for the return of waste from the used durable good back to County A.

An Import Tax on the Used Durable Good (t^A_w>0, t^B_w=0, t_m>0)

Assume that the government in Country B can levy a tax (t_m) on each unit of the used durable good imported from Country A. The consumer's budget constraint in Country B is therefore

$$M^B = (p_e + t_m)e + p_c c + p^B_w w^B.$$

The representative consumer maximizes utility in (5) subject to this budget constraint and the materials balance constraint $e = w^B$. The first-order conditions are

$$\mathcal{L}_{wb}: \quad U^B_e = \partial^B[p_e + t_m + p^B_w]$$

$$\mathcal{L}_c: \quad U^B_c = \partial^B[p_c],$$

which can be simplified to,

(19) $U^B_e/U^B_c = (p_e + t_m + p^B_w)/p_c$.

The representative competitive waste disposing firm in Country B no longer pays the disposal tax (t^B_w=0), but still charges market prices for disposal. Condition (17) therefore reduces to $p^B_w = p_k/b'$.

Following the same substitutions patterns described above, the allocation of resources as function of tax rates resulting from the competitive equilibrium is

(20a) $U^A_d/\partial^A = 1 + f'/g' + t^A_w$

(20b) $U^A_d/\partial^A = 1 + f'k^e - U^B_e f'/U^B_c h' + f'/b' + t_m$

By comparing (20) to the Pareto Opimal condition in (10), the optimal waste tax in County A (t^A_w) is unaffected and still equal to the external cost of disposal. But because County B is unable to assess a waste tax, the import tax is necessary for the decentralized economy to achieve the Pareto Optimum. The optimal import tax is set equal to the external marginal cost of waste disposal in Country B, as was the original waste tax from the previous section (thus, $t_m = t^B_w$). Both taxes (t_m and t^B_w) increase the overall cost of consuming the used durable good to the consumer in Country B. The consumer responds to either tax by substituting the non-durable good (c) for the used durable good (e) in consumption. This tax equivalency disappears if consumers in Country B face alternatives for disposing waste (currently $e = w^B$). If, for example, recycling were an option in Country B, then the waste tax would lead to efficient quantities of waste, consumption, and recycling, but the import tax would not lead to the efficient choice between waste and recycling.

A Subsidy to Waste Returns (t^A_w>0, t^B_w=0, t_e=0, t_r >0)

Consider an alternative policy approach where absent a disposal tax ($t^B{}_w$=0) the government in Country B can subsidize the return to Country A of the waste from the used durable good. Assume a technology is available to utilize the global economic resource (k^r) to transport the waste from the used durable back to Country A for disposal,

(22) $$w_r = r(k^r) \text{ where } r'>0.$$

The representative consumer in Country B now chooses whether to dispose the waste in Country B or return the waste to Country A, $e = w_B + w_r$ (with $w_B, w_r \geq 0$).

Based upon the materials balance constraints above, the total quantity of waste returned to Country A (call it R for the moment) is the total quantity of the used durable good exported to Country B (ne) less the total quantity disposed in Country B (mw_B). Because $e = w_B + w_r$, we have $R = n(w_B + w_r) - mw_B$, which can be simplified to $R = (n-m)w_B + nw_r$. The representative consumer in Country A experiences disutility from both sources of waste. Thus,

(23) $$U^A = U^A(d, nw_A + R) = U^A(d, nw_A + (n-m)w_B + nw_r),$$

All other tastes and technologies in this economy are identical to that modeled above.

The Pareto Optimal allocation of economic resources is found by maximizing the Lagrange function

$$\mathcal{L} = U^A\{g(k^w) + b(k^b) + r(k^r), ng(k^w) + (n-m)b(k^b) + nr(k^r)\}$$

$$+ \lambda_1[\overline{U}^B - U^B\{h[k - k^d - k^w - k^e(b(k^b) + r(k^r)) - k^b - k^r], b(k^b) + r(k^r), mb(k^b)\}]$$

$$+ \lambda_2[f(k^d) - g(k^w) - b(k^b) – r(k^r)],$$

Where $\overline{U}^B$ is a constant and λ_1 and λ_2 are Lagrange multipliers. This function is maximized over k^w, k^b, k^r, and k^d. The first-order conditions are

(24a) $$\mathcal{L}_{kw}: U^A{}_d g' + nU^A{}_w g' = \lambda_1[-U^B{}_c h'] + \lambda_2[g']$$

(24b) $\mathcal{L}_{kb}$: $U^A{}_d b' + (n\text{-}m)U^A{}_w b' = \lambda_1[-U^B{}_c h'k^{e}{}'b' - U^B{}_c h' + U^B{}_e b' + mU^B{}_w b'] + \lambda_2[b']$

(24c) $\mathcal{L}_r$: $U^A{}_d r' + nU^A{}_w r' = \lambda_1 [-U^B c\ h'k^{e}{}'r' - U^B{}_c h' + U^B{}_e r'] + \lambda_2[r']$

(25d) $\mathcal{L}_{kd}$: $\lambda_1[U^B{}_c h'] + \lambda_2[f'] = 0$

Divide (24a) by g', (24b) by b', (25c) by r', and solve (24d) for λ_1 and substitute into the three remaining conditions to get

(25a) $U^A{}_d/\lambda_2 + nU^A{}_w/\lambda_2 = f'/g' + 1$

(25b) $U^A{}_d/\lambda_2 + (n\text{-}m)U^A{}_w/\lambda_2 + mU^B{}_w f'/U^B{}_c h' = f'k^{e}{}' + f'/b' - U^B{}_e f'/U^B{}_c h' + 1$

(25c) $U^A{}_d/\lambda_2 + nU^A{}_w/\lambda_2 = f'k^{e}{}' + f'/r' - U^B{}_e f'/U^B{}_c h' + 1$

These three equations summarize the efficient global allocation of the economic resource. These conditions will be compared below with those representing a competitive economy.

In a decentralized economy, assume once again that the government of Country A can assess a tax on waste disposed in Country A ($t^A{}_w$), which would apply to both domestic waste and waste returned from Country B for disposal in Country A. Assume the only policy instrument in Country B is a subsidy ($s^B{}_r$) paid for the return of waste from the used durable goods originally exported from Country A. Although politically problematic, the subsidy could also be offered by the government of Country A if Country B lacks the administrative infrastructure to implement such an instrument.

In Country A, conditions for utility and profit maximization are identical to those stated in (11a), (11b), and (12) above. The waste disposal firm in Country A now receives waste from both Country A and Country B. This firm receives price, $p^A{}_w$, from consumers in Country A to dispose the durable good and price, p_r, from consumers in Country B to dispose the returned waste. The waste firm must pay the waste tax on both domestic waste (w_A) and waste returned from Country B (w_r). The waste firm employs the economic resource to facilitate two disposal technologies ((3) and now (22)) to maximize profit

$$\pi = (p^A{}_w - t^A{}_w)w_A + (p_r - t^A{}_w)w_r - p_k k^w - p_k k^r.$$

Profit is maximized by equating

(26a) $$p^A{}_w = (p_k/g' + t^A{}_w)$$

And

(26b) $$p_r = p_k/r' + t^A{}_w.$$

In Country B, the representative consumer chooses consumption and disposal practices to maximize utility (5) subject to the condition that $e = w_B + w_r$ and the budget constraint

$$M^B = p_e e + p_c c + p_r w_r + p^B{}_w w^B - s^B{}_r w_r,$$

where each unit of waste returned to Country A (w_r) receives the subsidy. The first-order conditions for utility-maximization are

(27a) $\mathcal{L}_c$: $U^B{}_c = \delta^B[p_c]$

(27b) $\mathcal{L}_{wb}$: $U^B{}_e = \delta^B[p_e + p^B{}_w]$

(27c) $\mathcal{L}_{wr}$: $U^B{}_e = \delta^B[p_e + p_r - s^B{}_r]$

Other profit-maximizing conditions representing the competitive economy in Country B are the same as above ((16) and (17), but with $t^B{}_w = 0$).

Solve for δ^B in (27a) and substitute into (27b) and (27c). Then use (16), (17), (26b), and (12) to eliminate p_c, $p^B{}_w$, p_r and p_k from the remaining two equations. Then use (12) and (26a) to eliminate p_k and $p^A{}_w$ from (11a) and (11b). (11a) becomes

(11a') $$U^A{}_d/\partial^A - t^A{}_w = f'/g' + 1$$

Then solve (11b) for p_e and substitute into (27b) and (27c) to eliminate p_e. The resulting equations are

(27b') $$U^A{}_d/\delta^A = f'k^{e'} + f'/b' - U^B{}_e f'/U^B{}_c h' + 1$$

(27c’) $U^A_d/\delta^A + s^B_r - t^A_w = f'k^{e'} + f'/r' - U^B_e f'/U^B_c h' + 1.$

Equations (11a’), (27b)’ and (27c)’ characterize the allocation of resources in a decentralized economy as a function of the waste tax in Country A and the subsidy for the return of waste in Country B. Notice that the right-hand sides of (11a’), (27b’) and (27c’) are equal to those of the Pareto Optimum, (25a), (25b) and (25c). Combining these two sets of three equations to eliminate the identical right-hand sides gives

(28a) $U^A_d/\lambda_2 + nU^A_w/\lambda_2 = U^A_d/\delta^A - t^A_w$

(28b) $U^A_d/\lambda_2 + (n\text{-}m)U^A_w/\lambda_2 + mU^B_w f'/U^B_c h' = U^A_d/\delta^A$

(28c) $U^A_d/\lambda_2 + nU^A_w/\lambda_2 = U^A_d/\delta^A + s^B_r - t^A_w$

Solve (28a) for t^A_w to get

$$t^{A*}_w = -nU^A_w/\lambda_2 - U^A_d(1/\lambda_2 - 1/\delta^A)$$

Only if $\lambda_2 = \delta^A$ (these re both Lagrange multipliers) will the waste tax in Country A be equal to the baseline case. Recall that λ_2 is the marginal utility of the durable good in County A and that that δ^A is the marginal utility of exogenous income in Country A. Given that the durable good is the numeraire (with price of 1) and is the only good that provides utility to the consumer in Country A, the addition of $1 in income to the consumer in County A must provide the equivalent marginal utility as the addition of one unit of the durable good. Thus the marginal utility of income will always equal the marginal utility of consuming the durable good, and $\lambda_2 = \delta^A$. Thus, the tax on waste is identical to the baseline case. Country A taxes waste according to external marginal cost of disposal in County A.

Set (28b) equal to (28c) by eliminating $(U^A_d/\lambda_2 - U^A_d/\delta^A)$ gives

$$s^{B*}_r = - mU^B_w f'/U^B_c h' - (n\text{-}m)U^A_w/\lambda_2 + nU^A_w/\lambda_2 + t^{A*}_w$$

which, when recalling that $f' = U^B_c h'/\delta^B$ (from (14), (16), and (12)) allows the optimal subsidy to be simplified to

$$s^{B*}{}_{r} = - m(U^{B}{}_{w}/\delta^{B} - U^{A}{}_{w}/\lambda_2) + t^{A*}{}_{w},$$

where $t^{A*}{}_{w}$ is defined as above.

There are three components to the optimal subsidy. The first we call the "Country B Effect", which suggests the optimal subsidy will reflect the external marginal cost of disposal in Country B ($-mU^{B}{}_{w}/\delta^{B}$). The subsidy increases the opportunity cost of disposing waste in Country B and therefore causes consumers to make efficient disposal decisions. The "Country A Effect" suggests the optimal subsidy should also reflect the external costs of returning waste to Country A ($U^{A}{}_{w}/\lambda_2$). This effect allows consumers in Country B to internalize the social disposal costs in Country A when choosing whether or not to return waste for disposal in Country A. The third component allows for perfect netting of the two policies. As the waste passes from the consumer in Country B to the disposal site in Country A, it will encounter two policy instruments ($s^{B*}{}_{r}$ and $t^{A*}{}_{w}$). This third component suggests that if the waste tax changes in Country A, then the subsidy should also change to leave constant the overall incentive to return waste to Country A.

Thus, two of these three components are based upon the external costs of disposal in Country A. To see this, substitute for $t^{A*}{}_{w}$ to find,

$$s^{B*}{}_{r} = - mU^{B}{}_{w}/\delta^{B} + (m-n)U^{A}{}_{w}/\lambda_2.$$

As external costs of disposal rise in Country A, the optimal return subsidy falls to discourage waste from being returned to Country A ($mU^{A}{}_{w}/\lambda_2$) and rises to preserve the zero-net-effect of the two policy measures ($-nU^{A}{}_{w}/\lambda_2$). The overall effect on the subsidy is positive if $n>m$ and is negative if $n<m$. Thus if the population of Country B is larger than that of Country A, then the value of the subsidy is inversely related to

external disposal costs in Country A.

Consider two interesting special cases. First, assume disposal technology in Country A has advanced to the point that all social costs of waste disposal are internalized by consumers paying the price of waste disposal. Thus, external costs of waste disposal are positive only in Country B ($U^A_w = 0$, $U^B_w/\delta^B > 0$). The optimal subsidy reduces to $s^{B*}_r = - mU^B_w/\delta^B$. The subsidy reflects the full external costs of disposal in Country B. Second, assume external costs of waste disposal are positive and equal in both countries ($U^A_w/\lambda_2 = U^B_w/\delta^B$). In this case $s^{B*}_r = t^{A*}_w$. The net incentive for returning waste to Country A is zero as the consumer receives the subsidy but must pay the equal tax for disposal in Country A. Once the waste material from the durable good is in Country B, society is indifferent between disposal in Country A or Country B.

Note that both instruments (t^A_w and s^B_r) allow the competitive economy to achieve the Pareto Optimal allocation of the economic resource. The return subsidy by itself is unable to achieve the Pareto optimum because it fails to force consumers in Country A to internalize the social costs of disposal. But if administering the return subsidy is impossible, then the next section examines the case when the only global policy instrument available is a waste tax (t^A_w) in Country A.

5. Only a Disposal Tax in Country A *(t^A_w>0, t^B_w=0, t_m=0)*

Suppose Country B is unable to assess the waste tax or the import tax, perhaps due a previous trade agreement. Mexico, for example, eliminated trade restrictions on all 10-15 year-old vehicles in 2005 in accordance with the implementation of NAFTA (Davis and Kahn (2008)). Furthermore, assume the technology to return waste to

Country A (in 22) is no longer available to the economy. The only remaining tax instrument available to the global economy is the disposal tax levied on waste disposed in County A.

The competitive decentralized allocation of the economic resource summarized in (20) is therefore reduced to,

(29a) $U^A_d/\partial^A = 1 + f'/g' + t^A_w$

(29b) $U^A_d/\partial^A = 1 + f'k^e - U^B_e f'/U^B_c h' + f'/b'$.

Note the only difference is that the t_m variable is now zero.

Recall that the Pareto Optimal allocation of resources is governed by (10). Comparing these two sets of equations suggests the Pareto Optimum can still be achieved by the single waste tax when

$$t^A_w = - nU^A_w/\lambda_2 + mU^B_w/\delta^B.$$

The waste tax in County A can be positive or negative depending upon the magnitudes of the waste externality in each country. The waste tax in Country A is negative (a subsidy) when $- mU^B_w/\delta^B > - nU^A_w/\lambda_2$, or when the waste disposal externality in Country B is larger than in County A. The waste subsidy serves to internalize to consumers in Country A the external costs of disposal in Country B. Consumers in Country A respond to the subsidy by efficiently reducing exports of the used durable goods to Country B. As was the case with the import tax discussed above, the efficiency of this waste tax relies upon there being no recycling options in Country B.

That an open country should set a waste tax waste above or below the domestic external cost of disposal has been found in previous studies, but for other reasons. Krutilla (1991) demonstrates that waste taxes are set above external marginal costs of disposal to reduce imports and therefore improve the terms of trade. Kennedy (1993) suggests waste taxes be set below the external marginal cost of waste to subsidize domestic industries. Cassings and Kuhn (2003) suggest waste taxes fall below the external marginal cost of waste to compensate for the market distortion caused by imperfect competition in the exporting country.

Consider the interesting case when the external disposal costs are equal across the two countries ($- mU^B{}_w/\delta^B = - nU^A{}_w/\lambda_2$). The optimal waste tax in this case is zero. The competitive market place void of tax policies results in the efficient allocation of the economic resource.

A government that disregards the external costs in Country B will set the waste tax equal to the external costs in Country A. This tax will cause consumers in Country A to inefficiently increase efforts to export the used durable good to Country B where tax policies do not exist. It is not clear that a government will ease domestic environmental policies to improve environmental conditions in other countries, as is called for to achieve a global Pareto Optimum.

5. Conclusion

This paper developed a model of two countries trading a used durable good for global reuse to solve for various tax systems that allow a competitive equilibrium to achieve the Pareto Optimal allocation of an economic resource. If the importing country is unable to tax waste according the external marginal cost of disposal, then the Pareto Optimum can be achieved by the implementation of an import tax or a subsidy paid for the return of the durable good for disposal in the original country. If the importing country is unable to tax imports or subsidize returns, then the Pareto Optimum can also be achieved by a single disposal tax in the exporting country. This tax is set below the external marginal cost of disposal in Country A to discourage consumers in Country A from exporting the used durable good to policy-less Country B.

Many developing countries that import used durable goods lack waste taxes, import taxes, or return subsidies. The remaining question is why. The lack of a waste could be due to worries over illegal dumping (Copeland, 1991). The absence of import taxes could be due to trade agreements, and the lack of a return subsidy might be attributable to the lack of public funds necessary to finance the subsidy. Lacking these policies, an inefficiently high quantity of waste from durable goods is disposed in developing countries. Perhaps the dead weight loss associated with the inefficiently high quantity of waste is small when compared to cost of administering a tax. Or perhaps government agents in developing countries do not internalize the social costs of disposal. Citizens bearing the external costs of disposal are unable to put public pressure on government.

References

S. P. Anderson and V. A. Ginsburgh, Price discrimination via second-hand markets, *European Economic Review* 38, 23-44 (1994).

S. Barrett, Strategic environmental policy and international trade, *Journal of Public Economics* 54, 325-38 (1994).

J. Cassing and T. Kuhn, Strategic environmental policies when waste products are tradable, *Review of International Economics* 11, 495-511 (2003).

B. R. Copeland, International trade in waste products in the presence of illegal disposal, *Journal of Environmental Economics and Management* 20, 143-162 (1991).

L. W. Davis and M. E. Kahn, International trade in used durable goods: The environmental consequences of NAFTA, NBER Working Paper 14565 (2008).

D. Fullerton and T. C. Kinnaman, Garbage, recycling, and illicit burning or dumping, *Journal of Environmental Economics and Management* 29, 78-91 (1995).

D. Fullerton and W. Wu, Policies for green design, *Journal of Environmental Economics and Management* 36, 131-148 (1998)

P. W. Kennedy, Equilibrium pollution taxes in open economies with imperfect competition, *Journal of Environmental Economics and Management* 27, 49-63 (1994).

T.C. Kinnaman, Optimal solid waste tax policy with centralized recycling, *National Tax Journal* 63(2), 237-252 (2010).

K. Krutilla, Environmental regulation in an open economy, *Journal of Environmental Economics and Management* 20, 127-42 (1991).

J. Puckett and T. Smith, “Exporting harm”, The Basel Action Network and Silicon Valley Toxics Coalition (2002).

J. Puckett, “The digital dump: Exporting re-use and abuse to Africa”, The Basel Action Network (2005).

M. Rauscher, International trade in hazardous waste, in “International environmental economics: A survey of the issues” (G. G. Schulze and H. W. Ursprung Ed.), Oxford Univ. Press, (2001).

T. Shinkuma, Reconsideration of an advanced disposal fee policy for end-of-life durable goods, *Journal of Environmental Economics and Management* 53, 110-121 (2007).

T. Shinkuma, Extended producer responsibility in a developed country and the effect on international trade, the environment, and social welfare, unpublished paper (2009)

R. D. Simpson, Optimal pollution taxation in a Cournot duopoly, *Environmental and Resource Economics* 6, 359-69 (1995).

V. M. Thomas, Demand and dematerialization impacts of second-hand markets, *Journal of Industrial Ecology* 7, 65-78 (2003).

H. -F. Yokoo, An economic theory of reuse, *Sustainability Science* 5, 143-150 (2010).

A. Yoshida, T. Tasaki and A. Terazono, Material flow analysis of used personal computers in Japan, *Waste Management* 29, 1602-14 (2009).

F. Yoshida, Information technology waste problems in Japan, *Environmental Economics and Policy Studies* 5, 249-260 (2002).

K. Wertz, Economic factors influencing households' production of refuse, *Journal of Environmental Economics and Management*, **2**, 263-72 (1976).

Recycling of Waste and Downgrading of Secondary Resources in a Linear Production Economy

Eiji Hosoda
Faculty of Economics
Keio University
2-15-45
Mita, Minato-ku
Tokyo 108-8345, JAPAN

4 June 2010

Abstract

This paper analyses recycling of waste and downgrading of secondary resources, using a classical type of linear production model. Residuals emitted as waste by households and secondary resources obtained by recycling of waste are negatively or positively priced, depending upon technological conditions and income distribution. In other words, they can be commodities (goods) or discommodities (bads), and the distinction cannot be determined by physical characteristics. How such distinction comes about is explained, based upon inter-industrial relationship and choice of technique. It is also demonstrated that per capita consumption may not necessarily be a decreasing function of a growth rate. This is an anomaly which cannot be found in an economy where discommodities or bads are not explicitly considered.

Keywords: commodity, discommodity, recycling, downgrading, choice of technique

1 Introduction

Piero Sraffa's *Production of Commodities by Means of Commodities* (1960) gives us a powerful analytical tool to explore the reproducible nature of a capitalist economy. Thanks to his contribution, complicated phenomena such as capital reversal, and re-switching of production technique and so on are illuminated. His method has a wide range of applicability, and environmental issues are no exception to the analytical target, although it has not been pursued at length in the Sraffian framework.

The purpose of this paper is to apply the method to an analysis of a waste management and recycling problem, which is one of the most important environmental issues. I demonstrate how choice of technique between waste disposal and recycling affects the natural price formation of an economy, and how waste and a secondary material become commodities (goods) or discommodities (bads), depending upon circumstances. I also show that choice of technique in a market economy leads to maximisation of per capita consumption as in the conventional model of a growing economy, if the profit rate equals the growth rate. Thus, it is shown that the golden rule of accumulation holds in this extended model. Furthermore, it is demonstrated that per capita consumption does not necessarily decreases as the profit rate increases. This is an anomaly which cannot be found in an economy where discommodities (bads) are not considered.

Although I have mentioned that the Sraffian method is not utilized sufficiently for studying environmental problems, I do not necessarily mean that there has been no contribution made by the method to the field of environmental analysis. On the contrary, quite a few researchers have contributed to this field insofar as a pure theoretical feature is concerned. Let us briefly refer to some of their works which are directly related to the present paper.

To the best of my knowledge, Franke (1986) is one of the first researchers who applied a Sraffian type of model to an environmental problem, although his model is so abstract that his work may not be regarded as being located in the stream of environmental economics. Yet, he abandons the free-disposal assumption and introduces a costly-disposal process in his paper. Apparently, this means that economic residuals, whether they be waste water, harmful gases, garbage or whatever, must be treated by a disposal process, and thus that he handles an environmental problem at an abstract level.

England (1986) also extends a Sraffian type of model on a rather earlier stage of the research history in order to present a basic model for analysing environmental problems such as air pollution, waste discharge and so on, although his treatment of the problems is very abstract, also. Using a very simple model, he shows how regulation on emission of economic residuals affects distribution of income, and how this type of model can be widely applicable to environmental problems.

Lager (2001) also tackles the costly-disposal problem in a more general framework. Elegantly using a linear complementarity theory, he shows that there exists a long-run equilibrium in a classical economics sense even if free disposal is restricted. A quite interesting aspect of his paper is that a distinction between commodities (goods) and discommodities (bads) is determined endogenously, so that materials become commodities (goods) or discommodities (bads), depending upon economic circumstances.

Kurz (2006) tackles a similar issue from a different angle. He surveys the traditional theory of joint production, finding that the costly-disposal problem can be handled in economics of the classical tradition. He also emphasizes that there is no *a priori* distinction between commodities (goods) and discommodities (bads).

Hosoda (2008) analyses the same problem as Lager's (2001) in a slightly different framework. Though Lager is more loyal to the original Sraffa system in adopting the assumption that the requirements for use is given, Hosoda inclines more to the analytical style of the Sraffa-Leontief-von Neumann framework. Hence, consumption demand is supposed to be dependent upon prices. As do other researchers, he demonstrates that a commodity (goods)/discommodity (bads) nature is determined endogenously in the model.

All the works mentioned above are more or less theoretical studies. Whereas they have some important conclusions for understanding the relationship between an economy and an environment, it is not so easy to deduce a concrete policy implication from those works. Being based upon them, Hosoda (2010a) applies the Sraffian framework to a more concrete environmental issue, namely a problem of waste management and recycling. He demonstrates why an upstream policy such as extended producer responsibility should be adopted to reduce household waste. He fully utilizes Sraffa's idea on a distinction between basic and non-basic commodities, and explains that such a policy is required only for household waste but not for industrial waste.

The present study follows the spirit of the above study, applying a Sraffian type of model to a very realistic feature of a recycling society where waste is recycled and recycled materials (secondary resources) are used as downgraded resources. Insofar as I know, how downgrade recycling affects price formation and per capita consumption has not been explored in a growing economy so far. I believe that this is the very issue to which the analysis based upon the classical tradition could be applied.

In the next section, the basic settings and assumptions are specified. In section 3, the main results are presented. It is shown how waste and a secondary material become commodities (goods) or discommodities (bads), depending upon technological conditions and income distribution. It is also demonstrated that per capita consumption may not be a decreasing function of a growth rate when the rate is sufficiently small. The concluding remarks are given in the final section.

Although I use a classical type of production model represented by a Sraffian model, I restrict our analytical framework to a more technologically specific one in order to make model building easier and clearer: a constant coefficient production model is adopted, and duality between price and quantity systems is emphasized. One more important feature of the present study is that most of the results are demonstrated by means of examples. Hence, mathematical deductions are relegated to the appendices.

2 The basic model and assumptions

2.1 A rough sketch of the model

Let us consider an economy where two different commodities are produced by two different production techniques. The first commodity is used only as an input to production processes (i.e., a commodity used as circulating capital only), and the second one is used only for consumption. Per capita consumption c is supposed to create residues or waste, which may be positively or negatively priced.

Waste treatment can be made by two processes, a disposal process and a recycling process. The former just disposes of waste in a harmless way, obtaining no product, whereas the latter transforms waste into a potential commodity, that is, a secondary material, which can be an alternative input to a production process of a commodity for consumption use. For simplicity, it is assumed that the secondary material cannot be used as an input to other production processes. Otherwise, things should be unnecessarily complicated.

The second commodity for consumption use (consumption goods) is, therefore, obtained by two production processes, namely the process which uses a brand-new capital commodity as an input and that which uses a secondary material as an input instead of a brand-new capital commodity. The two commodities for consumption use are differentiated as follows: The waste created by consumption of the first type can be recycled, but that of the second type cannot be, since the material embodied in the latter is supposed to be downgraded. Therefore, they are assumed to be the same as an object of consumption, but different on the post-consumption stage. It is supposed that the same amount of waste θc is discharged from per capita consumption c, whether consumption comes from the first type of production or the second type.

Let me give an example. Paper containers of a commodity for consumption use can be easily recycled if they are made of brand-new pulp, since the fibres contained in the paper are long and re-usable as an alternative input for brand-new pulp. On the other hand, it is not easy to recycle a used container which is made of used paper, since the fibres contained are sometimes too short to be recycled.

I do not insist that downgrading of used materials is a general character. It is easy to see that some materials such as gold, silver, platinum and other precious metals can be recycled without downgrading. Downgrade recycling is, however, common as seen in the example of paper recycling, and whether such recycling should be promoted or not becomes a hot issue on many occasions. This is why I analyse such recycling in this paper.

Let me remark on one more aspect of downgrading. In reality, there is gradation of downgrading of materials from perfectly recyclable quality to a non-recyclable one. Thus, downgrading is not a matter of recyclable-or-not. For instance, recyclability of used papers is quite varied, and recycled papers can be recycled again with downgrading quality. Clearly the most downgraded used paper must be disposed of.

Although it is desirable to reflect such gradation of downgrading quality of used materials in a model, I do not introduce such reality into the present one, since the model should be too complicated to be solved. Even a simple model which handles a recyclable-or-not nature tells us quite a few things, as shown later.

After explaining the basic structure of an economy, I can talk about techniques in this economy. There are two techniques, i.e., α-technique which consists of a production process of a commodity for input use, a production process of a consumption commodity which uses a brand-new input, and a disposal process, and β-technique which consists of a production process of a commodity for input use, production processes for consumption commodities which use a brand-new input and a secondary material input, and disposal and recycling processes.

An economy in which only α-technique is adopted is easy to handle, since it is an economy where a disposal process is activated in addition to ordinary production processes. Contrary to this, an economy where β-technique is adopted is somewhat difficult to deal with. One problem is that there are two types of waste, namely recyclable and non-recyclable waste. In order to promote proper recycling, one has to sort them. With appropriate provision of information on recyclability, such as labelling, written directions, TV PR and so on, one can easily sort different types of waste. Yet, there is a possibility that such information provision is incomplete and some households may mix two types of waste, whether intentionally or not.

In this paper, perfect sorting is assumed to prevail, so that households sort waste perfectly. Recyclable waste is handed over to a recycling process, and non-recycling waste to a disposal process. Although the assumption is slightly artificial, the model is still useful as a reference for understanding complicated reality. Relaxation of this assumption to accommodate imperfect sorting requires another laborious formulation. See Hosoda (2010b) in the extension of the model toward this direction.

2.2 Formal description of the model

Now, let me show the model. The technology of this economy is expressed as follows:

Table 1: A structure of production processes

	brand-new material	secondary material	waste	labour		brand-new material	consumption commodity	secondary material	waste
I	a_{11}	0	0	l_1	$\rightarrow$	1	0	0	0
II	a_{12}	0	0	l_2	$\rightarrow$	0	1	0	θ
III	a_{13}	0	b_3	l_3	$\rightarrow$	0	0	0	0
IV	a_{14}	0	b_4	l_4	$\rightarrow$	0	0	1	0
V	0	a_{15}	0	l_5	$\rightarrow$	0	1	0	θ

The first and second rows show a process which produces a commodity for input use by means of a brand-new material, and one which produces a commodity for consumption use, respectively. The third and fourth show disposal and recycling processes. The fifth row shows a process which produces a commodity for consumption use by means of a secondary material.

In the second and fifth rows, there are entries of waste which are represented by θ. This is because θ amount of waste is created by consumption of a unit of commodities which are produced by the second process (which uses brand-new input) and the fifth process (which uses secondary material as an input)[1]. The former waste can be treated by either the third process (the disposal process) or the fourth process (the recycling process), whereas the latter waste is treated only by the third process (the disposal process) due to the downgrading nature. Then, α-technique is expressed by the I to III processes, whereas β-technique by the I to V processes. It must be noted that a disposal process is operated with a recycling process side by side in β-technique, since there are two types of waste in this economy, i.e., recyclable and non-recyclable.

Let me mention another aspect of downgrading of a secondary material. As a production activity for consumption use, a process which uses a secondary material, that is, the IV process, is alternative to that which uses a brand-new one, that is, the II process. It is often seen that the former process is less productive than the latter in producing the same commodity, in the sense that more resources are used in the former than the latter. I would like to characterize the nature as $(a_{12}, l_2) < (a_{15}, l_5)$[2].

Let me summarize the nature of downgrading of a secondary material as follows:

Assumption 1 (Downgrading property)
1. Waste produced by consumption of a commodity which is produced by means of a secondary material cannot be recycled and must be disposed of, while that which is produced by means of a brand-new one can be recycled.
2. A production process of a consumption commodity which uses a secondary material as an input is less productive than that which uses a brand-new one, so that $(a_2, l_2) < (a_5, l_5)$ holds.

Economies represented by the two techniques are expressed as follows:

α-technique

Price system

The price system in this economy is expressed as

$$\begin{cases} (1+r)a_1 + wl_1 &= 1 \\ (1+r)a_2 + wl_2 &= p_2 \\ (1+r)\left(a_3 + p_3 b_3\right) + wl_3 &= 0, \end{cases} \tag{1}$$

where a_j, l_j and b_3 denote an input coefficient of a brand-new capital commodity and labour in the j-th process ($j = 1, 2, 3$), and a waste input coefficient in the third process (a disposal process), respectively, while r, w p_2 and p_3 denote a profit rate, a wage rate, a price of consumption commodity and a price of waste (negative) respectively. It is assumed that $a_1 < 1$ holds. This is required for an economy to be feasible.

[1] I assume that an activity of waste emission as well as a consumption activity is instant for simplicity.

[2] I adopt the following notation for vector inequalities. $x \equiv (x_1, \ldots, x_n) \leq y \equiv (y_1, \ldots, y_n)$ if $x_i \leq y_i$ for any $i (= 1, \ldots, n)$. $x \ll y$ if $x_i < y_i$ for any $i (= 1, \ldots, n)$. $x < y$ if $x \leq y$ and $x \neq y$.

A brand-new material used as a circulating capital is adopted as *numeraire*. The first and second equations express cost-price relationships of production of commodities for circulating-capital use and consumption use respectively. The third equation is a cost-price balance of a disposal process, which produces no output. Waste is inputted to the process with a negative price, and disposal operation is completed one period after the input. Hence, the profit factor $(1+r)$ is inserted before the term p_3b_3 as well as a_3.

Quantity system

On the other hand, the quantity system in this economy is expressed as

$$\left\{\begin{array}{rcl} (1+g)\,(a_1x_1+a_2x_2+a_3x_3) & = & x_1 \\ x_2 & = & c \\ (1+g)b_3x_3 & = & \theta c, \end{array}\right. \tag{2}$$

where g and x_j denote a growth rate and an activity level of the j-th process.

The first and second equations express the supply-demand balance of commodities for circulating capital use and consumption use respectively. The third equation is the supply-demand balance of waste. Demand for waste is supposed to come only from a disposal process.

Quantities are normalized by

$$l_1x_1+l_2x_2+l_3x_3=1.$$

Thus, all the quantities, as well as consumption c, are normalized by the total amount of labour, and c means per capita consumption.

β-technique

Price system

The price system of β-technique is expressed as follows:

$$\left\{\begin{array}{rcl} (1+r)a_1+wl_1 & = & 1 \\ (1+r)a_2+wl_2 & = & p_2 \\ (1+r)(a_3+p_3b_3)+wl_3 & = & 0 \\ (1+r)\,(a_4+p_3'b_4)+wl_4 & = & p_5 \\ (1+r)a_5p_5+wl_5 & = & p_2, \end{array}\right. \tag{3}$$

where a_4 and b_4 denote input coefficients of a brand-new material and waste for a recycling process, and p_3' denotes a price of waste (negative, zero or positive) respectively. A coefficient a_5 denotes an amount of a secondary material required for production of a unit of consumption commodity in the fifth process.

The first three equations are the same as those in (1). The fourth and fifth equations express a cost-price balance of a recycling process and a consumption-commodity production process which inputs a secondary material, respectively.

Quantity system

Now, the quantity system in β-technique is expressed as follows:

$$\left\{\begin{array}{rcl}(1+g)\,(a_1x_1+a_2x_2+a_3x_3+a_4x_4) & = & x_1\\ x_2+x_5 & = & c\\ (1+g)x_4b_4 & = & \theta x_2\\ (1+g)x_3b_3 & = & \theta x_5\\ (1+g)a_5x_5 & = & x_4.\end{array}\right. \tag{4}$$

The first and second equations express a supply-demand balance of a brand-new material (a circulating capital-commodity) and a commodity for consumption use. The third equation expresses that waste created by consumption of a commodity which is produced by means of a brand-new material is treated by a recycling process, while that created by consumption of a commodity which is produced by means of a secondary material must be treated by a disposal process, and this is expressed by the fourth equation. The fifth equation expresses a supply-demand balance of the secondary material.

A quantity normalization expressed by

$$l_1x_1+l_2x_2+l_3x_3+l_4x_4+l_5x_5=1$$

is supposed to be held.

2.3 Assumptions on choice of technique

Notice that processes I, II and III are common to both α- and β-techniques. The first commodity, i.e., a brand-new input, being adopted as *numeraire*, the wage rate, the price of a commodity for consumption use is also common to both techniques. The price of waste is, however, not common: Basically, p_3 is different from $p_3^{'}$. Apparently, the price of a secondary material p_5 appears only in an economy of β-technique.

Then, what is the principle of choice of technique in this economy? It must be noted that the wage-profit frontier is common to both techniques, expressed as

$$w=\frac{1-(1+r)a_1}{l_1}.$$

Therefore, a technique cannot be chosen by utilizing the frontier[3].

Now, let us consider choice of technique as follows: Suppose that $p_3^{'}>0$. Since p_3 is negative as easily seen from the third equation of (1) or (3), I assume that β-technique is chosen, since an economy where waste can be sold is considered to be more profitable than that where waste cannot be sold and must be disposed of with charge.

Suppose that $0\geq p_3^{'}>p_3$ holds. Then, waste is negatively priced (bads) by both disposal and recycling processes. Yet, it is cheaper to treat waste by a recycling process than a disposal process. Hence, I assume that β-technique is chosen, since an economy

[3]This is also true even if the second commodity is adopted as *numeraire*.

where waste is treated at a cheaper cost is considered to be more profitable than the other type of economy. Only when $0 > p_3 > p_3^{'}$ holds, I assume that α-technique is chosen, since it is cheaper to treat waste in a disposal process. Let me summarize the above as follows:

Assumption 2 (Hypothesis of choice of technique) *If $p_3^{'} > 0$ or $0 \geq p_3^{'} > p_3$ holds, β-technique is chosen. If $0 > p_3 > p_3^{'}$ holds, α-technique is chosen.*

Clearly, if $p_3^{'} = p_3$ holds, both techniques can be chosen, since they are equally profitable as far as waste treatment is concerned. It must, however, be noticed that this criterion of choice of technique is only on profitability of waste treatment and not on profitability of the whole economy. It will be shown later that the choice of technique based upon this hypothesis is not at all unreasonable, in the sense that the idea is a natural extension of the conventional economic model on choice of technique in a growing economy.

I would like to explain another assumption implicitly made in (1) and (3). It is assumed that waste is priced competitively in an economy, whether it be treated by a disposal process or a recycling process. This assumption might be regarded as a little strict, since disposal of household waste is usually made by municipalities instead of private firms, so that the price of waste may not be competitively priced.

Even so, it is quite important to know conditions of reproducibility of a capitalist economy where waste is created and must be treated. A natural price or a production price in a reproducible economy should be an important reference to a policy decision of waste management and recycling.

There is another justification. Nowadays, even the service of waste treatment is being privatized gradually in many countries. Particularly, as the supply-demand balance of natural resources is getting tighter and tighter, and as the cost of municipal waste service is increasing more and more, private firms are trying to enter into this business, making profits. Therefore, it is not so far-fetched to proceed with an analysis, as if the business were in the hands of private firms.

3 The analysis and the main results

In a linear production system which I present here, the so-called non-substitution theorem holds, so that a price system is dealt with independently of a quantity system. I, therefore, analyse the price system first.

3.1 The analysis of a price system

Let me show again the relationship between the profit rate and the wage rate, namely

$$w = \frac{1-(1+r)a_1}{l_1},$$

from which the maximum rate of profit R is known as $R = 1/a_{11} - 1$. This is common to both techniques. The prices of a commodity for consumption use and waste are easily calculated as

$$\begin{cases} p_2 = \dfrac{l_2 - (1+r)\,(a_1 l_2 - a_2 l_1)}{l_1} \\ p_3 = -\dfrac{l_3}{(1+r)b_3} + \dfrac{a_1 l_3 - a_3 l_1}{b_3}, \end{cases}$$

from which it is easy to know that p_2 is positive and p_3 is negative. It is well known that the price of a commodity for consumption use increases (decreases) if a capital-labour ratio (a_j/l_j) is larger (smaller) in the second process than the first as the profit rate increases. This is valid here, too. On the other hand, the price of waste is shown to be increasing with respect to the profit rate[4]. Thus, the waste disposal charge decreases as the rate of profit increases, since p_3 is negative.

Now, I would like to explore the price formation in β-technique. Let me deduce p_5 first before deduction of $p_3^{'}$. Clearly, p_5 is calculated as

$$\begin{aligned} p_5 &= \frac{(l_2 - l_5)\,\{1 - (1+r)a_1\}}{(1+r)a_5 l_1} + \frac{a_2}{a_5} \\ &= \frac{w(l_2 - l_5)}{(1+r)a_5} + \frac{a_2}{a_5}. \end{aligned} \tag{5}$$

If l_5 is very close to l_2, p_5 is positive. Moreover, considering that $(a_{12}, l_2) < (a_{15}, l_5)$, I can conclude that $p_5 \leq 1$. Thus, the following proposition is obtained:

Proposition 1 *The price of a secondary material is not greater than unity, i.e., than the price of a brand-new material for capital use, and positive if the value of l_5 is sufficiently close to that of l_2. Moreover, if both the values are the same, the price is a positive constant irrespective of the profit rate, and equals a_2/a_5. If the two values are different, the price increases as the profit rate increases.*

I can show the situation in the following figure. The minimum of p_5 is calculated as

$$p_5|_{r=0} = \frac{1}{a_5}\left\{(l_2 - l_5)(1 - a_1) + a_2\right\}.$$

This means that the price of the secondary material is positive for all the range of the profit rate if the value of l_5 is close to that of l_2, and a_2 is rather large (Fig 1-a). Otherwise, the price can be negative when the profit rate is very low (Fig 1-b).

//Fig.//

[4]This is clear from $\frac{dp_3}{dr} = \frac{l_3}{(1+r)^2 b} > 0$.

Next, the price of waste in an economy of β-technique is calculated as

$$p_3' = \frac{(1+r)\{a_2 - (1+r)a_4a_5\} + \{(l_2 - l_5) - (1+r)a_5l_4\}\,w}{(1+r)^2 a_5 b_4}. \tag{6}$$

The price of waste p_3' depends upon the profit rate r in a complicated way. Yet, the following is true:

Proposition 2 *Suppose $a_2 < a_4a_5$ holds. Then, the price of waste p_3' is always negative.*

Thus, in the case that productivity of a material input to the second process is relatively high compared to those to the fourth and the fifth processes, the price of waste is negative. The condition $a_2 < a_4a_5$ being coupled with $l_2 < l_5$, the waste input to a recycling process must be negatively priced. Negativity of p_3' implies that households have to pay for waste treatment service to a recycling process even if a recycled commodity or a secondary material can be sold in a market. Of course, p_3' can be positive, so that households may sell waste as a recyclable commodity to a recycling process.

Namely, the following holds:

Proposition 3 *Suppose $a_1a_2 > a_4a_5$ holds. Then, the price of waste p_3' is positive when the profit rate is near its maximum.*

See Appendix A for the proof.

Thus, p_3' is positive if material productivity of the recycling process coupled with that of the consumption-commodity production process with a secondary material input (i.e., $1/a_4a_5$) is large compared to material productivity of the production process of a commodity for a brand-new material use coupled with that of the production process of a commodity for consumption use by means of a brand-new input (i.e., $1/a_1a_2$), and if the profit rate is very large. Due to the assumption of downgrading ($a_5 \geq a_2$), the hypothesis in Proposition 3 implies a_4 is very small compared with a_1, meaning that the recycling process is very productive. Hence, if productivity of a recycling process is so large that the downgrading property of a secondary material is offset, p_3' can be positive.

What if the profit rate is very low? Is p_3' always negative? Not necessarily, as shown in the following proposition:

Proposition 4 *Suppose a_1 is sufficiently close to unity. Then, the price of waste p_3' is positive if $a_2 > a_4a_5$ holds, and the wage rate is near its maximum (the profit rate is very low).*

See Appendix A for the proof.

From the above propositions, it is known that the price of waste treated by the recycling process in an economy of β-technique can be positive or negative, depending upon circumstances. As seen by the above propositions, it can be positive or negative, depending upon the relative magnitudes of the coefficients. Moreover, I can show that a switch of positiveness and negativeness may possibly depend upon the distribution income.

Suppose that the hypothesis of proposition 3 is satisfied so that $a_1a_2 > a_4a_5$ holds. Furthermore, suppose that l_5 is sufficiently large. Then, the price of waste in β-technique p'_3 is negative when $r = 0$ or $w = w_{max} \equiv (1 - a_{11})/l_1$, as seen from (6). Yet, it turns to positive when r is near its maximum. Thus, globally, the price of waste in β-technique p'_3 increases as the profit rate increases, although this relationship may not hold locally. Hence, both p'_3 and p_5 increase as the profit rate increases in a global sense if the above condition is satisfied.

The following table shows how p'_3 and p_5 become positive or negative. It must be noticed that p'_3 is always negative when p_5 is negative.

Table 2: Signs of p'_3 and p_5

	$(-)$	$(+)$
p'_3	$a_2 < a_4a_5$	(i) $a_1a_2 > a_4a_5$ and r is close to R (ii) $a_2 > a_4a_5$, a_1 is close to 1 and r is close to 0
p_5	$\dfrac{a_2}{l_5 - l_2} < \dfrac{1 - a_1}{l_1}$ and r is close to 0	$\dfrac{a_2}{l_5 - l_2} > \dfrac{1 - a_1}{l_1}$

Finally in this subsection, let me mention how p'_3 changes as the profit rate increases. Although it is not easy to deduce a general rule for the movement since p'_3 changes in a complicated way, I can show an interesting result in a special case. If a labour input to a recycling process is relatively larger than that to a production process for a brand-new material, the price of waste in β-technique (p'_3) increases as the profit rate increases, as shown in the following proposition:

Proposition 5 *If $l_4 \geq l_1$, then p'_3 increases as the rate of profit increases.*

See Appendix A for the proof.

3.2 Numerical examples

Let me show some examples which demonstrate how the price formation is made. In the following, $\theta = 1$ is assumed.

Example 1

$a_1 = \frac{4}{5}\ l_1 = \frac{1}{10},\ a_2 = \frac{1}{2}\ l_2 = \frac{1}{2},\ a_3 = \frac{1}{2}\ b_3 = \frac{1}{10}\ l_3 = \frac{1}{2},\ a_4 = \frac{1}{2}\ b_4 = \frac{1}{2}\ l_4 = 1,$
$a_5 = \frac{1}{2}\ l_5 = \frac{2}{3}.$

When the profit rate is zero, then $w = 2,\ p_2 = \frac{3}{2},\ p_3 = -15,\ p_3' = -\frac{13}{3}$, and $p_5 = \frac{1}{3}$. Since $p_3' > p_3$ holds, β-technique is chosen. The price of waste is negative, while that of a secondary material is positive.

Example 2

$a_1 = \frac{4}{5}\ l_1 = \frac{1}{10},\ a_2 = \frac{1}{10}\ l_2 = \frac{1}{2},\ a_3 = \frac{1}{2}\ b_3 = \frac{1}{10}\ l_3 = \frac{1}{2},\ a_4 = \frac{1}{2}\ b_4 = \frac{1}{2}\ l_4 = 1,$
$a_5 = \frac{1}{2}\ l_5 = 1.$

When the profit rate is zero, then $w = 2,\ p_2 = \frac{10}{11},\ p_3 = -15,\ p_3' = -\frac{43}{5}$, and $p_5 = -\frac{9}{5}$. Since $p_3' > p_3$ holds, β-technique is chosen. Yet, in this case, both the prices of waste and secondary material are negative. Even so, β-technique is chosen, according to the hypothesis of choice of technique (Assumption 1).

Example 3

$a_1 = \frac{99}{100}\ l_1 = \frac{1}{10},\ a_2 = \frac{1}{2}\ l_2 = \frac{1}{2},\ a_3 = \frac{1}{2}\ b_3 = \frac{1}{10}\ l_3 = \frac{1}{2},\ a_4 = \frac{1}{2}\ b_4 = \frac{1}{2}\ l_4 = 1,$
$a_5 = \frac{1}{2}\ l_5 = \frac{2}{3}.$

When the profit rate is zero, then $w = \frac{1}{10},\ p_2 = \frac{11}{20},\ p_3 = -\frac{11}{2},\ p_3' = \frac{11}{15}$, and $p_5 = \frac{29}{30}$. Since $p_3' > 0$ and $p_5 > 0$ hold, β-technique is chosen. Waste as well as a secondary material is traded as a normal commodity (goods).

Example 4

$a_1 = \frac{4}{5}\ l_1 = \frac{1}{10},\ a_2 = \frac{1}{2}\ l_2 = \frac{1}{2},\ a_3 = \frac{1}{2}\ b_3 = 1\ l_3 = \frac{1}{2},\ a_4 = 1\ b_4 = \frac{1}{20}\ l_4 = 1,$
$a_5 = \frac{4}{5}\ l_5 = \frac{2}{3}.$

When the profit rate is $\frac{1}{4}$, then $w = 0,\ p_2 = \frac{5}{8},\ p_3 = -\frac{1}{2},\ p_3' = -10$, and $p_5 = \frac{5}{8}$. Since $p_3 > p_3'$ holds, α-technique is chosen, even if the price of a secondary material is positive in an economy of β-technique.

3.3 Quantity system

In this subsection, the quantity system is analysed. First, from (2), activity levels of α-economy are obtained as follows:

$$x_1 = \frac{(1+g)a_2 b_3 + \theta a_3}{\{1-(1+g)a_1\}\, b_3} c \tag{7}$$

$$x_2 = c \tag{8}$$

$$x_3 = \frac{\theta}{(1+g)b_3} c, \tag{9}$$

where c denotes per capita consumption and $\sum_{i=1}^{3} l_i x_i = 1$ must hold. These are the activity levels of α-technique.

From (4), activity levels of β-technique are obtained as follows:

$$x_1 = \frac{(1+g)^3 a_2 a_5 b_3 b_4 + \theta^2 a_3 + (1+g)^2 \theta a_4 a_5 b_3}{\{1-(1+g)a_1 a_5 b_3 b_4 (1+g)^2\}} x_2 \tag{10}$$

$$x_2 = \frac{(1+g)^2 a_5 b_4}{(1+g)^2 a_5 b_4 + \theta} c \tag{11}$$

$$x_3 = \frac{\theta^2}{b^3 (1+g)^3 a_5 b_3 b_4} x_2 \tag{12}$$

$$x_4 = \frac{\theta}{(1+g) b_4} x_2 \tag{13}$$

$$x_5 = \frac{\theta}{(1+g)^2 a_5 b_4} x_2, \tag{14}$$

where $\sum_{i=1}^{5} l_i x_i = 1$ must hold.

Coupling (7)-(9) with $\sum_{i=1}^{3} l_i x_i = 1$, the activity levels of the long-run steady state of α-technique as well as per capita consumption c are obtained. In the same way, coupling $\sum_{i=1}^{5} l_i x_i = 1$ with (10)-(14) with $\sum_{i=1}^{5} l_i x_i = 1$, those of β-technique are obtained. It is easy to see all the obtained variables are positive if g is smaller than the maximum rate (R). Thus, the following holds:

Proposition 6 *If the growth rate is smaller than the maximum rate given by R, all the activity levels and per capita consumption in the long-run steady state are positive.*

According to the hypothesis shown in 2.3 (Assumption 2), the technique is chosen on the side of the price system, namely, by comparison of p_3 and p_3'. The quantity system follows this choice of technique. Notice I have adopted the assumption that the quality of a secondary material is downgraded compared to that of a brand-new material. Then, it might be supposed that per capita consumption in β-technique (denoted by c_β) is smaller than that in α-technique (denoted by c_α), due to the downgrading nature of a secondary material. Things are not so simple: The former may be larger or smaller than the latter, depending upon circumstances, as shown later by means of numerical examples. Even if a secondary material is downgraded in the sense of Assumption 1, per capita consumption in β-technique can possibly be larger than that in α-technique if productivity of a recycling process is sufficiently high.

Another interesting point on the quantity system is that there is an anomaly which cannot be seen in the conventional model, where per capita consumption is considered to decrease (increase) as the growth rate increases (decreases). This relationship does not necessarily hold in an economy where waste is disposed of or recycled. In the present model, per capita consumption may increase (decrease) as the growth rate increases (decreases) in a certain interval of the growth rate, although there is always a trade-off relationship between the wage rate and the profit rate.

To grasp the situation, let us consider the conventional multi-sectoral steady state model, where per capita consumption measured by each activity level, namely c/x_i, decreases as the growth rate increases[5]. In other words, an activity level measured by per capita consumption x_i/c increases as the growth rate increases. This implies that $\sum_{i=1}^{n} l_i(x_i/c)$ also increases as the growth rate increases. Since this term is nothing but a reciprocal number of per capita consumption, per capita consumption decreases as the growth rate increases. The important point in deducing this result is that each activity level measured by per capita consumption increases (or does not decrease) as the growth rate increases.

This no longer holds anymore in the present model. First, consider the α-technique. As clearly seen from (9), an activity level of a disposal process measured by per capita consumption (x_3/c) decreases as the rate of growth increases. The reason is as follows: If the growth rate increases, demand for a waste input to a disposal process also increases, requiring more waste than before. Thus, more per capita consumption is required insofar as the waste emission coefficient θ is constant. Consequently, if the labour coefficient of a disposal process expressed by l_3 is large compared to l_1 and l_2, per capita consumption increases as the growth rate increases. This, however, happens when the growth rate is low, and a downward relationship between the growth rate and per capita consumption is kept when the growth rate is near its maximum. This could be intuitively understood by the fact that $c = x_2 = 0 (= x_3)$ holds when $g = g_{max} \equiv R$ and $c > 0$ when $g = 0$. That is, the downward relationship holds globally, but may not hold locally.

The same is true for the β-technique, although things are a little more complicated. Since x_3 is calculated as

$$x_3 = \frac{\theta^2}{\{(1+g)^2 a_5 b_4 + \theta\}(1+g) b_3} c,$$

it is easily known that x_3/c decreases as the growth rate increases. Notice that this logic applies to an activity level of the fifth process:

$$x_5 = \frac{\theta}{(1+g)^2 a_5 b_4 + \theta} c$$

holds, and x_5/c decreases as g increases.

Hence, for the same reason mentioned above, per capita consumption increases as the growth rate increases if the labour coefficients of the third (a disposal) and/or fifth processes are large compared to other labour coefficients. Again, this relationship holds when the growth rate is low, and the downward relationship between the growth rate and per capita consumption holds when the growth rate is near its maximum[6].

[5]Notice that at least one c/x_i is constant.

[6]For a precise deduction, see Appendix B.

3.4 Choice of technique and per capita consumption: Numerical examples

In the previous subsection, I have mentioned that choice of technique is made on the side of the price system. Thus, it is natural to ask whether the choice may lead to maximum per capita consumption in a certain condition such as $r = g$. I would like to explain this by means of numerical examples. In the following examples, $\theta = 1$ is supposed.

First, let me go back to *Example 3* in 3.2. Namely,

$$a_1 = \tfrac{99}{100}\ l_1 = \tfrac{1}{10},\ a_2 = \tfrac{1}{2}\ l_2 = \tfrac{1}{2},\ a_3 = \tfrac{1}{2}\ b_3 = \tfrac{1}{10}\ l_3 = \tfrac{1}{2},\ a_4 = \tfrac{1}{2}\ b_4 = \tfrac{1}{2}\ l_4 = 1,$$
$$a_5 = \tfrac{1}{2}\ l_5 = \tfrac{2}{3}.$$

In this case, β-technique is chosen, since p_3' is positive. Easy calculation shows that $c_\alpha = 0.0177$ and $c_\beta = 0.0214$ when $g = 0$. Per capita consumption in an economy of β-technique is larger than that of α-technique. Choice of technique due to the hypothesis (Assumption 2) brings about larger per capita consumption.

The same is true for *Example 4*, i.e.,

$$a_1 = \tfrac{4}{5}\ l_1 = \tfrac{1}{10},\ a_2 = \tfrac{1}{2}\ l_2 = \tfrac{1}{2},\ a_3 = \tfrac{1}{2}\ b_3 = 1\ l_3 = \tfrac{1}{2},\ a_4 = 1\ b_4 = \tfrac{1}{20}\ l_4 = 1,$$
$$a_5 = \tfrac{4}{5}\ l_5 = \tfrac{2}{3}.$$

In this example, α-technique is chosen, since $0 > p_3 > p_3'$ holds. It is easy to see that $c_\alpha = 0.6667 > c_\beta = 0.3929$. Thus, choice of technique due to the hypothesis gives a larger per capita consumption.

Now, let us consider the following example.

Example 5

$$a_1 = \tfrac{4}{5}\ l_1 = \tfrac{1}{10},\ a_2 = \tfrac{1}{2}\ l_2 = \tfrac{1}{2},\ a_3 = \tfrac{1}{2}\ b_3 = \tfrac{1}{10}\ l_3 = \tfrac{1}{2},\ a_4 = \tfrac{3}{8}\ b_4 = \tfrac{2}{15}\ l_4 = \tfrac{1}{2},$$
$$a_5 = \tfrac{4}{5}\ l_5 = 1.$$

Suppose $r = g = 0$ and $\theta = 1$. Then, $w = 2$, $p_2 = \frac{3}{2}$, $p_3 = -15$, $p_3' = -15$ and $p_5 = -\frac{5}{8}$ are obtained. Since $p_3' = p_3 (< 0)$ holds, both techniques can be chosen according to the hypothesis. Per capita consumption in both techniques is $c_\alpha = c_\beta = \frac{4}{33}$. This example suggests an interesting feature of a recycling economy. Although the waste treatment charge in the waste disposal process is the same as that in the recycling process, the price of a secondary material is negatively priced in the β-technique economy. This implies that a secondary material in this economy can be regarded as a discommodity or bads. The fifth process has a property of waste treatment in this sense. Waste discharged by households can be transformed into a commodity or goods only after the two-stage treatment. Even so, the amount of per capita consumption is the same in both economies.

The above examples allude to the fact that choice of technique based upon the hypothesis (Assumption 2) realizes the maximum per capita consumption, and that the golden rule of accumulation applies to this model. Actually, this is true in the present model. The following proposition is obtained:

Proposition 7 *Suppose $r = g$. Then, $p_3 \gtreqless p_3' \Leftrightarrow c_\alpha \gtreqless c_\beta$ holds.*

See Appendix C for the proof.

This proposition gives us justification for the hypothesis of choice of technique stated in Assumption 2, since it is the natural extension of the conventional result on per capita consumption in a growing economy: If the profit rate equals the growth rate, per capita consumption is maximised by choice of technique in a market.

4 Concluding remarks

Using a classical type of linear production model, I have analysed an economy where waste disposal and recycling activities are performed, and where the quality of a secondary material is downgraded, compared to a brand-new material. It is shown that prices of waste and a secondary material can be positive or negative, depending upon technical conditions, as well as income distribution.

Based upon the hypothesis that a technique is chosen by the comparison of prices of waste or waste treatment charges, I have demonstrated that per capita consumption is maximised in a market economy and the golden rule holds if the profit rate equals the growth rate. This may be regarded as natural extension of the conventional result on per capita consumption in a growing economy.

One anomaly found in the present model is that both the growth rate and per capita consumption may increase when the growth rate is low. Economic growth means an increase in the activity level of the disposal process, and this requires more waste input to the process. This effect is, however, offset by a rapid increase in the activity level of a brand-new capital-commodity production process when the growth rate is very high, since there is no room for an increase in per capita consumption, and therefore waste.

The present model is very simple, but demonstrates quite a few points which have not been explored by mainstream economic theory. In this sense, one may say that a classical type of linear production model, represented by a Sraffian model, is powerful to in investigating waste disposal and recycling problems. Further development on this line will surely contribute to daily policy-making processes of waste management.

A Appendix

In this appendix, I show how Propositions 3, 4 and 5 hold.

Proof of Proposition 3.

Suppose $r = R$ $(w = 0)$. Then,

$$\text{Numerator of } p_3' = (1+R)a_2 - (1+R)^2 a_4 a_5.$$

Since $1 + R = \frac{1}{a_1}$, the above equals

$$\frac{a_2}{a_1} - \frac{1}{a_1^2} a_4 a_5 = \frac{1}{a_1^2}(a_1 a_2 - a_4 a_5).$$

Hence, $a_1 a_2 > a_4 a_5$ is equivalent to $p_3' > 0$. ∎

Proof of Proposition 4.

Suppose $r = 0$ $(w = w_{max})$. Then,

$$\text{Numerator of } p_3' = (a_2 - a_4 a_5) + \{(l_2 - l_5) - a_5 l_4\} \frac{1 - a_1}{l_1}.$$

Hence, if a_1 is sufficiently close to unity, the second term of the above may be ignored, and p_3' is positive. ∎

Proof of Proposition 5.

Notice

$$p_3' = \frac{\{a_2 - (1+r)a_5 a_4\} + \{(l_2 - l_5) - (1+r)a_5 l_4\} \frac{w}{1+r}}{(1+r)a_5 b_4}$$

holds. Considering

$$a_1 + \frac{w}{1+r} l_1 = \frac{1}{1+r}$$

and, thus,

$$\left(\frac{w}{1+r}\right)' (1+r) = -\frac{1}{(1+r)l_1}$$

hold, the numerator of $a_5 b_4 (dp_3'/dr)$ is calculated as

$$\frac{a_5 l_4}{l_1} - a_2 + \frac{1}{1+r}\left(\frac{1}{l_1} + w\right)(l_5 - l_2)$$

holds, where the denominator is $(1+r)^2$. Since $l_5 \geq l_2$ and $a_5 \geq a_2$ by hypothesis, and a strict inequality holds in either expression,

$$l_4 \geq l_2 \Rightarrow \frac{a_5 l_4}{l_1} \geq a_5 \geq a_2,$$

which means $dp_3'/dr > 0$. ∎

B Appendix

In this appendix, I show how both the growth rate and per capita consumption increase when the growth rate is low. Let me start from α-technique. Equations (7)-(9) can be rewritten as $x_1 = \varphi_1(g)c$ and $x_3 = \varphi_3(g)c$. Coupling these with $\sum_{i=1}^{3} l_i x_i = 1$ and differentiating this, we have

$$c'(g) = -\frac{l_1\varphi_1'(g) + l_3\varphi_3'(g)}{\{l_1\varphi_1(g) + l_2 + l_3\varphi_3(g)\}^2}.$$

It is easy to show that $\varphi_1'(g) > 0$, $\varphi_3'(g) < 0$, $\lim_{g\to R}\varphi_1'(g) = +\infty$ and $\varphi_3'(R) > -\infty$. Thus, we have $c'(R) < 0$, which means the downward relationship between the growth rate and per capita consumption holds when the growth rate is near its maximum. Yet, if g is sufficiently small,

$$l_1\varphi_1'(g) + l_3\varphi_3'(g) > 0$$

holds for sufficiently small l_1, which means that $c'(0) > 0$. Thus, both the growth rate and per capita consumption increase when the growth rate is very small.

∎

Next, β-technique. (10)-(14) are rewritten as $x_1 = \phi_1(g)x_2$, $x_2 = \phi_2(g)c$, $x_3\phi_3(g)x_2$, $x_4 = \phi_4(g)x_2$ and $x_5 = \phi_5 x_2$. Clearly,

$$c'(g) = -\frac{l_1\left(\phi_1(g)\phi_2(g)\right)' + \phi_2'(g) + l_3\left(\phi_3(g)\phi_2(g)\right)' + l_4\left(\phi_4(g)\phi_2(g)\right)' + l_5\left(\phi_5(g)\phi_2(g)\right)'}{\{l_1\phi_1(g)\phi_2(g) + l_2\phi_2(g) + l_3\phi_3(g)\phi_2(g) + l_4\phi_4(g)\phi_2(g) + l_5\phi_5(g)\phi_2(g)\}^2} \tag{15}$$

holds. Set the numerator and denominator of $\phi_1(g)$ as $A(g)$ and $B(g)$ respectively, and set the numerator of $\phi_1'(g) \equiv C(g)$. Clearly, $C(g) = A'(g)B(g) - A(g)B'(g)$ holds. Notice $A(g)$ contains a term $\{1-(1+g)\}$ which vanishes as g goes to its maximum ($= g_{max} \equiv R \equiv 1/a_{11} - 1$). Then, $C(g)$ goes to

$$\left[(1+g)^3 a_{13}a_{15}b_4 + \theta^2 a_{13} + a_{15}b_3(1+g)\left\{(1+g)a_{14} + 1\right\}\theta\right] a_{11}a_{15}b_3b_4(1+g)^2 > 0$$

as $g \to R$. Moreover, the following is obtained:

$$\begin{aligned}\left(\frac{x_1}{c}\right)' \quad = \quad & \frac{(1+g)a_{15}b_4}{[\{1-(1+g)a_{11}\}a_{15}b_3b_4(1+g)^2]}\frac{1}{[(1+g)^2a_{15}b_4+\theta]} \\ & \times\left[\frac{C(g)(1+g)}{\{1-(1+g)a_{11}\}a_{15}b_3b_4(1+g)^2} - \frac{2(1+g)a_{15}b_4\theta A(g)}{(1+g)^2a_{15}b_4+\theta}\right].\end{aligned}$$

The second term in the square bracket above is bounded, while the first term goes to $+\infty$, since $C(g)$ goes to a positive constant. Therefore, (x_1/c) goes to $+\infty$, which means c/x_1 is negative for sufficiently large g.

Finally, it is easy to show that $(\phi_3(g)\phi_2(g))' < 0$ and $(\phi_5(g)\phi_5(g))' < 0$. Therefore, if l_3 and/or l_5 are sufficiently large compared to other labour coefficients, $c'(g)$ is positive from (15).

∎

C Appendix

Proof of Proposition 7.

Notice that the wage rate and the price of a commodity for consumption use (p_2) are common to both economies. Denote $x_{ij}(i = 2, 5$ and $j = \alpha, \beta)$ as the activities corresponding to each technique. Then, the following must hold:

$$\begin{cases} w + p_3\theta x_{2\alpha} & = & p_2 x_{2\alpha} \\ w + (p_3'\theta x_{2\beta} + p_3\theta x_{5\beta}) & = & p_2(x_{2\beta} + x_{5\beta}) \end{cases}$$

from which

$$(p_2 - \theta p_3)x_{2\alpha} = p_2(x_{2\beta} + x_{5\beta}) - \theta(p_3' x_{2\beta} + p_3 x_{5\beta})$$

must hold. Since $p_2 - \theta p_3 > 0$ holds,

$$p_3' \gtreqless p_3 \Leftrightarrow c_\alpha = x_{2\alpha} \gtreqless x_{2\beta} + x_{5\beta} = c_\beta$$

is obtained. ∎

References

[1] England, R.W. (1986) "Production, Distribution, and Environmental Quality: Mr. Sraffa Reinterpreted as an Ecologist", *Kyklos*, Vol. 39, pp. 230-44.

[2] Franke, R. (1986) "Some Problems Concerning the Notion of Cost-Minimizing Systems in the Framework of Joint Production", *The Manchester School*, Vol. LIV, No. 3, pp. 298-307.

[3] Hosoda, E. (2008) "Bads as Joint Products in a Linear Production System", forthcoming in *Production, Distribution and Trade* ed. by Adriano Birolo *et. al.* (Routledge), pp. 33-61.

[4] Hosoda, E. (2010a) "Malfunction of a Market in a Transaction of Waste - A Reason for the Necessity of an Upstream Policy in Waste Management", contained in *Economic Theory and Economic Thought - Essays in Honour of Ian Steedman* ed. by John Vint, *et. al.* (Routledge), pp. 234-253.

[5] Hosoda, E. (2010b) "Sorting and Recycling of Waste in a Neo-Ricardian Model", Keio University (mimeo).

[6] Kurz, D. H. (2006) "Goods and bads: Sundry observations on joint production, waste disposal, and renewable and exhaustible resources", *Progress Industrial Ecology - An International Journal*, Vol. 3, No. 4, pp. 280-301.

[7] Lager, C. (2001) "Joint Production with 'Restricted Free Disposal'", *Metroeconomica*, Vol. 52, No. 1, pp. 49-78.

[8] Sraffa, P. (1960) *Production of Commodities by Means of Commodities*, Cambridge University Press.

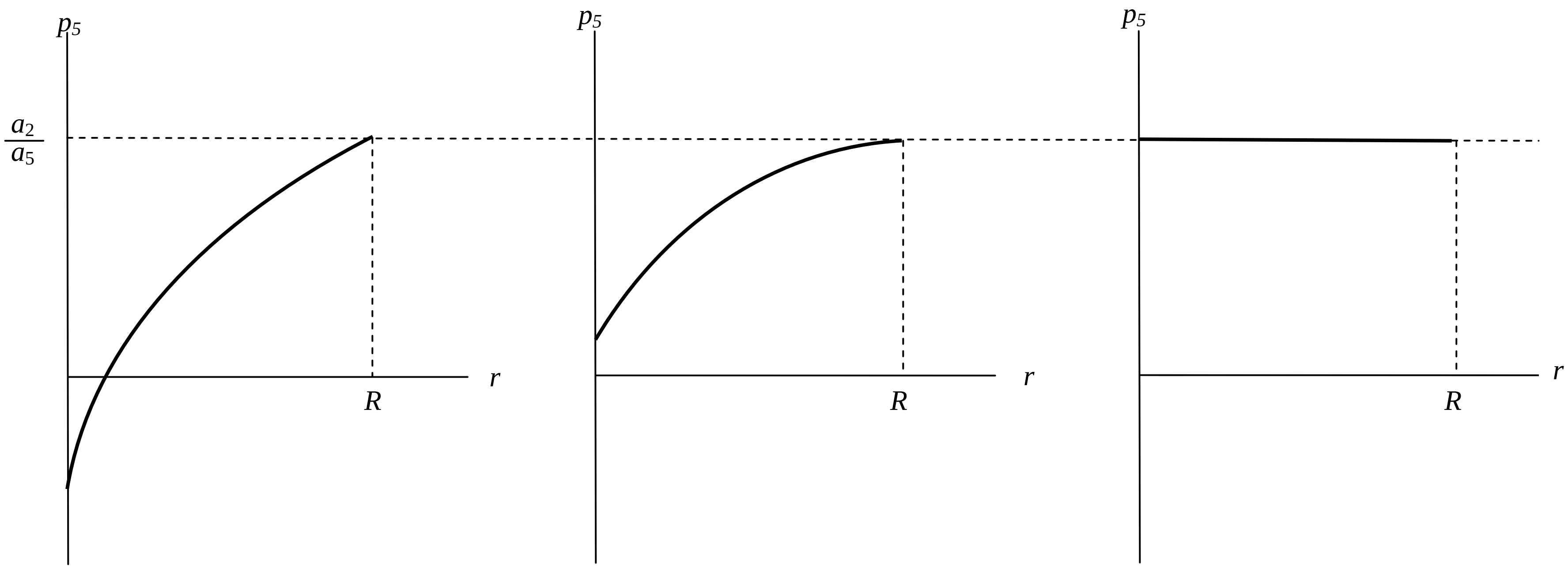


Fig. 1-a ($l_5 > l_2$; l_5 is not close to l_2.) Fig. 1-b ($l_5 > l_2$; l_5 is close to l_2.) Fig. 1-c ($l_5 = l_2$)

Is a voluntary program an effective instrument for Japan?

Omata Yukiko

Abstract

In this paper, I examine incentives for firm participation in a voluntary program in Japan and the impact of this program on chemical substances form firms. I find that firms with higher R&D expenditures and lower advertising expenditures are likely to participate in a voluntary program in Japan compared to firms with lower R&D expenditures. I also find that participants in the voluntary programs do decrease their targeted air toxic emissions, and the program is thus effective in reducing targeted toxic air emissions.

Keywords: Voluntary program; program evaluation; PRTR

1. Introduction

It is not easy to obtain public acceptance when introducing conventional environmental policy instruments such as the command-and-control and environmental taxes. Thus, public voluntary programs, which encourage firms to improve their environmental performance, have been advocated. Under these programs, regulators establish the framework and the basic requirements for participation; polluters that participate in the program are generally able to choose which abatement strategies to use in meeting environmental targets.

In Japan, the government requested that each industry reduce hazardous air pollutants and thus established a voluntary program to encourage the reduction of hazardous air pollutants from 1997 to 1999 and from 2001 to 2003. This program targeted 12 chemicals chosen by the government. Under this program, each industry set the pollution reduction targets with which the participants had to comply. There were 77 industry groups. The government did not provide firms with technical assistance nor financial support. Firms that participated in the program had to report their efforts in reducing their program emissions to their industry group, and the industry group had to report the total reduction amounts to the government. This program was not legally binding and there was no legal basis for sanctioning defecting firms.

There are several previous empirical studies that explore the motivations for participating in voluntary programs and whether the EPA's voluntary program is said to be successful in the United States.

Arora and Cason (1996) examine the factors that motivate firms to participate in the EPA's 33/50 program. This program aims to reduce the transfer and chemical release of 17 high-priority pollutants by 33% in 1992 and by 50% in 1995. Firms individually committed and pledged to reduce the transfer and release of these chemicals in the United States. These authors find that public recognition is an important incentive for firms to participate in the program.

Videras and Alberini (2000) explore why firms participate in the 33/50 program. They reveal that publicity is an important determinant of participation, as is correcting a poor environmental track record on behalf of the firm.

Khanna and Damon (1999) find that participation in the 33/50 program led to a decline in toxic releases. Further, while the program had a negative impact on firms' current return on investment, it had a positive impact on the expected long-run profitability of firms.

Rabindran (2006) shows that participants increased off-site transfers to recyclers in several key industries. He also finds that participants do not reduce their health-indexed emissions of targeted chemicals.

Vidovic and Khanna (2007) examine firm participation in the 33/50 program and the impact of this program on firm emissions in the manufacturing industry. They find that firms with high pollutants are likely to participate in the program and the decline in emissions was the result of an independent trend rather than a direct consequence of the program.

However, little research has been conducted on the incentives for firm participation in a voluntary program and whether such voluntary programs would be successful in Japan.

The purpose of this study is to explore the incentive for firm participation and the impact of the program on the release of targeted and non-targeted chemical substances. This study also aims to evaluate the effectiveness of the program using the facility-level data regarding the release and transfer of chemical substances collected under the Pollutant Release and Transfer Register (PRTR) system in Japan. The PRTR program was likely to fail in reducing the overall chemical risk due to a reduction in the release of targeted chemical substances by substituting them with non-targeted ones.

This paper is organised into four sections. The first section explains the econometric model in Section 2 and describes the data in Section 3. Section 4 presents the estimation results, and the final section provides conclusions.

2. Empirical model

In this study, I examine the incentive for firm participation in the program (participation model) by first using the probit model. Then, I develop emission models of targeted and non-targeted chemical substances to explore the impact of the program on the emissions.

The participation model is expressed as follows:

$$DHAP_{it}^{*} = \alpha_0 + \alpha_1\left(\frac{Advertise}{sales}\right)_{it} + \alpha_2\left(\frac{R\&D}{sales}\right)_{it} + \alpha_3 size_{it} + \sum_j \alpha_j DIND_j + \varepsilon_{it}$$

where *DHAP** indicates the net benefit of the firm's participation in the program. I do not observe $DHAP_{it}^{*}$, but only note whether the firm participated or not. Thus, firms participate if $DHAP_{it}^{*} \geq 0$; otherwise, they do not participate.

Advertising, *sales*, *R&D*, *size*, and *DIND$_j$* denote the firm's advertising expenditure, the firm's sales, the firm's R&D expenditure, the firm's total assets, and the dummy variable of industry j, respectively. ε_{it} is the error term and is normally distributed with a mean of zero and variance equal to one.

Firms that interact more closely with consumers are more likely to participate in a voluntary program. As in a previous study, I proxy this consumer contact with the ratio of advertising expenditure to sales. If the coefficient of the advertising expenditure to sales is positive in the participation model, this suggests that firms with high advertising expenditures per unit of sale are likely to participate in a voluntary program due to consumer loyalty.

The degree of firm innovation is represented by the inclusion of R&D expenditure per unit of sale. R&D expenditure per sales is calculated by dividing research and development expenditures by sales. Because R&D expenditure per sale may be found to positively correlate with a firm's participation in the program, it is included as a control. Firms with greater existing R&D expenditures per sale may find it less costly to allocate additional resources to environmental R&D; thus, the coefficient of R&D expenditures per sale will be positive in the participation model.

The firm's size is calculated as the log of the total assets. Larger firms may be more likely to participate because they are more visible and have stable profitability. I predict that this coefficient is positive in the emissions model.

I create dummy variables for firms in three industries with high PRTR releases, which are chemicals, non-metal, and machine.

Emission models of targeted and non-targeted chemical substances are expressed as follows:

$$\mathrm{Re}\,leases_{it}^{k} = \beta_0 + \beta_1 DHAP_{i,t-1} + \beta_2\left(\frac{Advertise}{sales}\right)_{it} + \beta_3\left(\frac{R\&D}{sales}\right)_{it} + \beta_4 \ln size_{it}$$
$$+\beta_5 foreign_{it} + \sum_j \beta_j DIND_j + v_{it}$$

where *Releases*^{k} (k = t or n) indicates the release of targeted chemical substances for k = t and those of non-targeted substances for k = n. *Foreign* denotes the ratios of the foreign stockholders.

In estimating the emission models, I use the predicted probability of firm participation rather than *DHAP*, using the estimation results of the participation model to avoid a self-selection bias. I lag *DHAP* by one year to avoid simultaneity in modelling the relationship between firm emissions and the firm's participation decision.

Dependent variable is used in the emissions model for *Release*.

I define releases of targeted chemical substances as the aggregate of 12 targeted chemicals released into the air. The 12 chemicals include acrylonitrile, chloroethylene, vinyl chloride, 1,2-dichloroethane, chloroform, methylene dichloride, tetrachloroethylene, trichloroethylene, benzene, formaldehyde, acetaldehyde, 1,3-butadiene and nickel compounds.

I examine not only quantity-based results but also toxicity-based results (Tons×Toxicity weight). I employ the EPA's inhalation toxicity score[1] for releases into the air and oral toxicity scores for all other releases to examine toxicity-based results. The EPA's toxicity score indicates how a chemical compares with others in terms of its capacity to cause chronic human health effects. I define the release of targeted chemical substances with toxicity weight as the weighted aggregate of 12 targeted chemical released into air.

Releases of non-targeted chemical substances are calculated by subtracting the amount of the targeted 12 chemical substances from the total amount of emissions to air.

These measures capture the efficiency of production processes and prevention, and are standardised by firm size. It would be preferable to use product amount rather than sales for their variables, but this data is not available.

I include a number of control measures commonly used in the analysis of emission models.

The coefficient of the advertising expenditure per sale will be negative in the emission model because firms with high advertising expenditures per sale are likely to reduce emissions due to consumer loyalty.

---

[1] The U.S. EPA is developing Risk-Screening Environmental Indicators (RSEI) to calculate comparative, risk-related scores. For details about the RSEI, see the EPA's website at http://www.epa.gov/oppt/rsei/index.html.

The coefficient of R&D expenditure per sale is anticipated to be negative. Highly innovative firms are likely to realise savings and efficiencies in the production process. Khannna, Quimio, and Bojilova (1998) find weak support that greater R&D intensity leads to a reduction in TRI chemical emissions. As a result, I predict that the effect on emissions will also be positive in Japan.

The coefficient of firm size is anticipated to be negative because large firms are more visible and have stable profitability. It is predicted that this coefficient will be negative in the emissions model.

I use the share of foreign ownership of the total number of stocks to indicate the pressure on reducing chemical emissions from foreign investors. The coefficient of the share of foreign ownership is predicted to be negative because foreign investors prefer green firms. Greater pressure from foreign investors may encourage firms to reduce environmental emissions.

2. Data

Firm-level financial data for firms listed in the Nikkei 300 stock index were obtained from the Nikkei Needs database. The Nikkei 300 is the stock index created by Nikkei Inc. and is composed of 300 companies listed on Japanese stock exchanges. Industries represented in the sample include food and beverage, pulp and paper, chemical, pharmacy, oil, tuber, steel, non-metal, machinery, metalworking, electrical equipment, automobile, electrical machinery, precision instrument, textiles, transportation, construction, and gas. Annual releases and transfers of the firms were obtained from the Ministry of the Environment's PRTR database. Quantities of toxic releases were aggregated and matched merged at the firm level. After eliminating the missing data, the full sample included 145 firms. I use pooled data from 2001 to 2003.

I conducted e-mail surveys and telephone surveys. As a result, I collected data from 58 firms that participated in the voluntary program; 86 firms did not participate. One firm did not disclose whether it participated in the program.

Unfortunately, it is not possible to get the firms' chemical data from 1997 to 1999 because the PRTR system began in 2001. Thus, I evaluate this program from 2001 through 2003.

4. Estimation Results

4.1.Program participation

I first examine firm participation in the participation model. Table 2 presents these results. The coefficient for advertising expenditure per sale is negative and statistically significant. This finding indicates that firms with lower levels of consumer contact are more likely to participate.

The coefficient for R&D expenditure per sale is positive and statistically significant. This finding suggests that firms with a higher R&D expenditure per sale are more likely to participate.

The coefficient for firm size, as measured by the log of total assets, is not statistically significant. This finding indicates that firm size does not affect a firm's decision to participate in the program.

4.2. Program impact

Table 3 presents the results on the program impact. Column 1 presents the regression results for predicted participation in reducing emissions of the targeted 12 toxic chemicals and column 2 presents regressions of predicted participation in reducing the hazardous adjusted emissions. Column 3 presents regressions of the predicted participation I reducing the non-targeted emissions.

As seen in Table 3, column 1, the coefficient for R&D expenditure per sale is positive and statistically significant. This finding suggests that the firms with a higher R&D expenditure per sale have lower levels of emissions for the 12 targeted chemicals.

The coefficient for the advertising expenditure per sale is negative and statistically significant. This result indicates that firms with a higher level of consumer contact are likely to have lower levels of the targeted 12 chemical emissions.

The coefficient for firm size, as measured by the log of total assets, is not statistically significant. This finding indicates that firm size does not affect firms' targeted emissions.

The coefficient for the ratio of foreign stakeholders is not statistically significant. This result indicates that firms with a higher ratio of foreign stakeholders have lower levels of the targeted emissions.

The coefficient on the predicted probability of participation is negative and statistically significant. This finding suggests that participation in the program led to a decrease in targeted chemical emissions.

As evident in Table 3, column 2, the coefficient for R&D expenditure per sale is positive and statistically significant. This finding shows that the firms with higher R&D expenditure per sale have lower levels of targeted emissions with hazardous toxicity.

The coefficient for the advertising expenditure per sale is negative and statistically significant. This result indicates that firms with higher levels of consumer contact are likely to have lower levels of targeted emissions with hazardous toxicity.

The coefficient for firm size is not statistically significant. This finding indicates that firm size does not affect firms' targeted emissions with hazardous toxicity.

The coefficient for the ratio of foreign stakeholders is not statistically significant. This result indicates that firms with a higher ratio of foreign stakeholders have lower levels of the targeted emissions with hazardous toxicity.

The coefficient for the predicted probability of participation is not statistically significant. This finding suggests that participation in the program does not lead to a decrease in targeted chemical emissions with hazardous toxicity.

In Table3, column 3, the coefficient for R&D expenditure per sale is positive and statistically significant. This finding shows that firms with a higher R&D expenditure per sale have lower levels of targeted emissions compared with non-targeted emissions.

The coefficient for the advertising expenditure per sale is negative and statistically significant. This result indicates that firms with higher levels of consumer contact are likely to have lower levels of targeted emissions compared with non-targeted emissions.

The coefficient for firm size is not statistically significant. This finding indicates that firm size does not affect firms' targeted emissions compared with non-targeted emissions.

The coefficient for the ratio of foreign stakeholders is not statistically significant. This result indicates that firms with a higher ratio of foreign stakeholders have lower levels of the targeted emissions compared with non-targeted emissions.

The coefficient for the predicted probability of participation is not statistically significant. This finding suggests that participation in the program does not lead to a decrease in targeted chemical emissions compared with non-targeted emissions. Compared to the targeted emissions case, this finding indicates that firms do not increase non-targeted emissions while decreasing targeted emissions.

5. Conclusions

First, I explore the incentives for the firms' participation. I find that firms with greater R&D expenditures per sale are likely to participate. This finding suggests that firms have an incentive to participate in the program because firms can easily move resources to work on pollution prevention for the program's targeted toxic chemicals. In addition, I find that firms with lower levels of consumer contact are likely to participate. This result is not consistent with the previous stud, which found that firms have an incentive to participate in the voluntary program because they are sensitive to consumer perceptions. Furthermore, I find no evidence that larger firms are more likely to participate than smaller firms.

Next, I explore the impact of the program on the release of targeted and non-targeted chemical substances, respectively. I find that firms that participate in the program reduce their emissions of the program's targeted chemicals. There is no evidence that firms decrease targeted emissions while increasing non-targeted emissions.

Thus, I conclude that the voluntary program, which encouraged reduction of hazardous air pollutants from 2001 to 2003 in Japan, was successful. In addition, I find that high levels of consumer contact are important incentives for reducing not only targeted emissions but also non-targeted emissions.

Despite the increasing prevalence of voluntary programs in the United States and European countries, the use of this instrument is limited in Japan. This analysis provides clues that voluntary programs can be used as tools for pollution reduction in Japan.

References

S. Arora, T.N. Cason, Why do firms volunteer to exceed environmental regulations? Understanding participation in EPA's 33/50 program. Land Economics 72 (1996) 413-432.

M. Khannna, W.R. Quimio, and D. Bojilova, Toxic release information: A policy tool for environmental protection. Journal of Environmental Economics and management 36 (1998) 243-266.

M. Khanna, L.A. Damon, EPA's voluntary 33/50 program; impact on toxic releases and economic performance of firms, Journal of Environmental Economics and Management 37 (1999) 1-25.

S. Gamper-Rabindran, Did the EPA's Voluntary industrial toxics program reduce emissions? A GIS analysis of distributional impacts and by-media analysis of substitution. Journal of Environmental Economics and Management 52 (2006) 391-410.

J. Videras and A. Alberini, The appeal of voluntary environmental programs: which firms participate and why?, Contemporary Economic Policy, Western Economic Association International.18 (2000) 449-460.

M. Vidovic and N. Khanna, Can voluntary pollution prevention programs fulfill their promises? Further evidence from the EPA's 33/50 Program. Journal of Environmental Economics and Management 53(2007) 180-195.

Table 1

Descriptive statistics

Variables	Mean	Standard deviations
R&D/sales (ratio)	0.039	0.043
Advertising/sales (ratio)	0.011	0.017
Size	13.246	1.371
Foreign (ratio)	0.058	0.15
Releases of the targeted chemical substances (tons)/sales (millions yen)	0.128 12.174	0.500 45.012
Releases of the targeted chemical substances with toxicity weight (tons)/sales (millions yen)	0.730	3.449
Releases of non-targeted chemical substances (tons)/sales (millions yen)		

Table 2

Determinants of firm participation in the program

Variables	
R&D/sales	3.97
	(2.37)**
Advertising/sales	−9.44
	(−1.91)*
Size	0.08
	(1.44)
Chemical	1.59
	(7.16)***
Non-metal	0.41
	(1.66)*
Machine	0.58
	(2.88)**
Intercept	−1.55
	(−2.01)**
Log-Likelihood	−227.84
Wald statistic	72.17***
Pseudo R squared	0.14

***, ** and * indicate statistical significance at the 1% level, the 5% level and the 10% level, respectively; t-value in parentheses.

Table 3

Program impact

Dependent Variables	The targeted chemical substances	The targeted chemical substances with toxicity weight	The non-targeted chemical substances
R&D/sales	0.71	106.53	1.69
	(2.48)**	(2.13)**	(0.90)
Advertising/sales	−4.29	−832.89	−26.45
	(−2.21)**	(−2.45)**	(−2.09)**
Size	0.02	3.64	0.12
	(1.09)	(1.20)	(0.92)
Foreign	0.07	0.74	0.11
	(0.66)	(0.04)	(0.16)
Chemical	0.63	111.41	3.36
	(2.04)**	(2.06)**	(1.65)*
Non-metal	0.12	18.44	0.44
	(1.09)	(1.00)	(0.86)
Machine	0.15	28.88	0.80
	(1.03)	(1.17)	(0.16)
Predicted probability of	−0.96	−164.70	−4.65
participation	(−1.69)*	(−1.62)	(−1.22)
Intercept	0.14	14.24	0.49
	(1.13)	(0.65)	(0.49)
F-statistics	3.38***	3.68***	3.51***
Adj. R-squared	0.05	0.06	0.05

***, ** and * indicate statistical significance at the 1% level, the 5% level and the 10% level, respectively; t-value in parentheses.

Cost-Effective Control of Ground-Level Ozone Pollution in and around Beijing

Xuxuan Xie, Shiqiu Zhang, Jianhua Xu, Dan Wu, Tong Zhu

College of Environmental Sciences and Engineering, Peking University, No. 5 Yiheyuan Road, Haidian District, Beijing, 100871, P. R. China

Correspondence to: Shiqiu Zhang (zhangshq@pku.edu.cn)

Abstract

Ground level ozone pollution has become a concerned air pollution problem in Beijing. Because of the complex way in which ozone is formed, it is difficult for policy makers to identify optimal control options on a cost-effective basis. This paper identifies and assesses a range of options for addressing this problem. We apply the Ambient Least Cost Model and compare the economic costs of control options, then recommend the most effective sequence to realize pollution control at the lowest cost. The study finds that installing of Stage II gasoline vapor recovery system at Beijing's 1,446 gasoline stations would be the most cost-effective option. Overall, options to reduce ozone pollution by cutting vehicular emissions are much more cost-effective than options to "clean up" coal-fired power plants.

Key words: Ground level ozone pollution, Ambient Least Cost Model, Beijing

1 Introduction

The severe ground-level ozone pollution problem as menifested by the frequently-occuring photochemical smog requires the actions to abate its precursors. However, the highly non-linear relationship between ground-level ozone and its percursors (NOx and VOCs) makes it difficult to develop effective options to abate ground-level ozone. Ground-level ozone is produced by the reaction of NOx and VOCs, and under favorable meteoroglical conditions ground-level ozone can be accumulated and then transported over considerable distance. The contribution of ozone transported from surrounding industrial provinces to Beijing’s ozone pollution has been identified by Streets et al. (2007), and Wang et al (2009). Streets et al. (2007) estimated that about 35–60% of ozone during high ozone episodes can be attributed to sources outside Beijing. While Wang et al (2009) proved that the transport of ozone was responsible for about 70% of the regional ozone contribution to Beijing urban areas, and transport of ozone precursors accounted for the remainder. This regional transportation of ozone even further complicated the problem of identifying effective options to abate ozone pollution in Beijing.

Although the ground-level ozone pollution in Beijing has been identified since the 1980s (Tang et al. 1995; Sun et al., 2004; Ding et al. 2008; Xu et al. 2008), the efforts for addressing ground-level ozone pollution has been limited. In the 1980s and the earlier 1990s, the major environmental targets was “dust” and “smoke” from coal-burning which caught more attention aesthetically at that time. In the late 1990s, the deterioration of air pollution triggered the development of a “master environmental plan” for imporving the air quality in Beijing. The bidding for and staging of the 2008 Olympics had been a catalyst for the implementation of these plans. Since then, substaintial efforts have been made to clean the air in Beijing. There measures include increasing access to natural gas, electricity, and geothermal energy; converting all coal-burning stoves and residential boilers to cleaner energy; and enforcing more stringent emission standards for vehicles. To assure the air quality during the Olympics meet the promised standards, additional temoporary and long-term measures have been taken to improve the air quality, which include reducing coal consumption, installing emission control equipment, increasing natural gas use, tightening vehicle emission standards, and introducing airborne PM and evaporative VOC controls (Peking University 2007). Albeit these substantial efforts are being made to imporve the air quality in Beijing, the long-term mechanism for abating ground-level ozone pollution has not been developed yet. As one of the precursors of ground-level ozone, nitrogen dioxide has been routinely monitored and more often than not ambient nitrogen dioxide meets the CNAAQS. Thus, in the past, the abatement of nitrogen oxides has not been among the priority list in the agenda. As the other important precursor of ground-level ozone, VOCs was given limited attention as well in the past.

Concerning of the social resource constrain, cost effective control strategies have been studied on air pollution control (e.g. Atkinson and Lewis 1974, Newell and Stavins 2003, Cofala et al 2004). However as the complicated non-linear and regional pollution process, economical control strategies for ground ozone pollution have been studied relatively much less by researchers (Krupnick and Portney 1991, Street et al. 2001, Shih et al. 2003, Guariso, Pirovanob and Volta 2004), and to our best knowledge, no similar study has been conducted in developing coutries yet. In this paper, we follow the ambient least cost model constructed by Atkinson and Lewis (1974) which is able to solve the non-uniformly mixed air pollution problems, and compare the economic costs of control options, then recommend the most effective sequence to realize pollution control at the lowest cost.

2 Methods

The Ambient Least Cost (ALC) Model is applied to track the path of selected control measures, based on the identification of pollution and emission sources as well as optional measures and their costs. The model shows the relationship between local emissions and the receptor's ozone concentrations, and the optimization process, which are described in the following sections.

The optimization processes are discussed in four steps. First, we chose the baseline scenarios, calculated the emissions amounts and simulated the ozone pollution situation (using the index of Maximum Hour-Concentration of atmospheric ground level ozone). Next, we formed the conversion factors matrix and established a relationship between local emissions and the receptor's (Beijing's) ozone concentration; Third, the control targets for ozone pollution are set up. And finally, we used the Ambient Least Cost Model to determine the optimal control path by using different types of control measures/policies.

2.1 Baseline and Control Scenarios

This paper aimed at calculating and comparing the future effects and costs of different control measures. The emission amounts in the future are simulated based on emission sources inventory of 2005 (industrial sources) and 2007 (vehicles, paint use, gasline stations, and the others sources). We chose 2010 and 2015 as the baseline scenario years. Because China has the “Five-Year Development Plans” for social and economic development every five years, and the 11th Five-Year Development Plan will end in 2010, when the 12th plan will begin. The latter will end in 2015. Due to the rapid development and changes in the economy of Beijing, we could not predict too far into the future. So we choose 2010 and 2015 as the short and medium-term baseline scenarios.

2.2 Conversion Coefficients

An integrated assessment model for ozone pollution, like the Ambient Least Cost (ALC) Model or the Regional Air Pollution Information and Simulation (RAINS) Model, needs to be able to relate ozone concentration in recepter to changes in the emissions of ozone precursors. Several ways of condensing the results of more complex models of ozone formation in order to construct a simplified means of representing source-receptor relationships are possible but we used conversion factors, which are also used to describe the important relationships between ozone and its precursors. Similar method has been applied in other researches of non-uniformly mixed air pollution problems (Krupnick and el al. 2000, Cofala and et al. 2004). It must be kept in mind that, in the overall context of an integrated assessment model, the aim of such an approach is merely to provide source-receptor relationships which are computationally efficient so as to enable a cost and optimization analysis of alternative emission reduction strategies to be made. The conversion coefficients were determined by three parameters: Area parameters, Precursor parameters and the height of emission sources.

For the area parameters, Miao used the MM5-CAMx model and ozone source identification technology (OSAT), and simulated the contribution to ozone concentration in Beijing and surrounding areas, using motoring data from August 2006. The results revealed that, downtown Beijing, Southern Hebei, and the Southern city districts and counties of Beijing had the biggest effect on maximum hour average ozone concentration, with a contribution rate of 32.4%, 14.8%, and 14.5% respectively. Meanwhile, the vehicles sources, VOC unorganized sources (including paint use, gasoline stations and natural sources) and power plants contributed to Beijing's ozone volumes by 42%, 14%, and 8.5%, respectively.

For the precursor parameters, we adopted the results of "Research on the characteristics of pollutant transportation and reaction in Beijing and surrounding areas and air quality control strategies" (hereafter named as Beijing program, Peking University 2007), with one of the main conclusions being that Beijing was a VOC-dominated ozone pollution area, which means due to the high concentration of NOx, NOx amount is excessive for the chemical reaction between NOx and VOC in the atmosphere, so the amount of VOC is limit to the ozone production. However, if the NOx concentration declines or VOC concentration increases, NOx can become the dominator. So, for long-term control strategies, NOx should be controlled with VOC too. According to the coefficients of relation founction between ozone concentration and NOx and VOC concentrations, we set the contribution effect of VOC as twice as effect of NOx.

For high level emission sources, Li, Hao and Hu (2005) modeled the contribution of power plants and vehicles to ozone concentration in Beijing, and estimated the relationships between NOx emitters and concentration. We calculated the average of their results and obtained a contribution of 8.7% by power plants and 63.9% by vehicles, and determined the relationship between ozone concentration and high-level emission sources (like power plants) and low-level emission sources (like vehicles), respectively, at 1.048(ug/m3)/10,000 tonnesand 7.879(ug/m3)/10,000 tonnes.

2.3 Control Targets

The damage effects of ozone pollution are different from other ordinary pollutants such as SO2 or NOx. A short-duration ozone explosion can cause disease and harm to plant life. So the World Health Organization (WHO) uses the maximum one-hour mean concentration (MHMC) measurement; every hour has a mean concentration of ozone and choose the maximum from among the 24 hours in a day, to show the ozone pollution situation and health risk of the day. WHO set 160 ug/m^3 as the one-hour concentration limit for a day in the even of an ozone explosion. If the MHMC of one day is higher than 160 ug/m^3, there will be health risks, and such a day exceeding the one-hour concentration limit is called an Exceeding Day (ExD). The WHO counts the number of ExDs in one year or in August (because usually the most serious ozone pollution happens in August due to the high temperature in China) to show the ozone pollution situation in different places. It also counts the total hours exceeding the one-hour concentration limit, and calls these Exceeding Hours (ExHrs) in the whole year or in August to show the ozone pollution situation in different places. In 2005, WHO changed its air quality guidelines from the one-hour concentration limit to an eight-hour mean concentration limit because scientists proved that a longer time period’s (8 hours specifically) ozone explosion caused more significant damage to human health and plant life. However, in China, there still only exist air quality standards using the one-hour concentration limit for ozone pollution. So in this study, we only considered the MHMC, ExDs, and ExHrs as the indices of ozone pollution.

As China's air quality standards use the one-hour limit, 160 ug/m^3, for the China Air Quality National Standard I for Ozone Concentration (CNSO I), and 200 ug/m^3 for CNSO II (almost 93 ppb), we set 160 ug/m^3 as the long-term ozone concentration limit to satisfy CNSO I and 200 ug/m^3 to satisfy CNSO II. Based on our analysis of the monitoring and observation data for 2007 under the Beijing Program (Peking University 2007), the maximum one hour mean concentration (MHMC) limit for ozone reached about 326 ug/m^3. Meanwhile, we estimated the MHMCs of the 2010 and 2015 baseline scenarios were 285 ug/m^3 and 276 ug/m^3, respectively.

2.4 Optimization

The mathematical optimization method is based on the emissions abatement potential, control options cost data and contribution to the recipient from emission sources, and identifies optimal cost control scenarios to achieve the environmental objectives. The ALC Model was first proposed by Atkinson and Lewis (1974). It minimizes the cost of different sectors' pollution control techniques in different areas under set constraints and targets.

The minimum cost objective function is:

$$MinC = \sum_{i=1}^{N} \sum_{t=1}^{Ti} ((u_i * e_{i,t}) * c_{i,t} * x_{i,t}) \qquad \text{(Equation 1)}$$

The objective function aims at total cost minimization. Equation 2 shows that the atmospheric pollutant concentration in the recipient location at least equals the reduction targets. Equations 3 and 4 show that among the control measures applied to all sources of emissions of pollutants, each source can only have one control measure.

$$\Psi[\underline{u}, \underline{e}, \underline{x}] \geq S_j, \forall j = 1, M \qquad \text{(Equation 2)}$$

$$x_{i,t} \in \{0,1\}, \forall i = 1, N; t = 1, T_i \qquad \text{(Equation 3)}$$

$$\sum_{t=1}^{T} x_{i,t} = 1, \forall i = 1, N \qquad \text{(Equation 4)}$$

where C: the total control cost; I: the number of pollution sources; t: the kind of technology in use; u_i : the emission level without any control measures; $e_{i,t}$: the reducing efficiency in pollution source I using technology t; $c_{i,t}$: the cost per every emission reduction in pollution source i, using technology t; $x_{i,t}$: a dummy, when using technology t it is 1, if not it is 0; j: the number of recipients; u: a set of all kinds of pollution emissions; e: a set of pollution reductions; Ψ: the predicting pollutants concentration in the recipient; and S_j : the reduction target.

An S-R matrix is used to predict the ozone concentration changes in the receptors from emission amount changes in sources. The S-R matrix is a N*M matrix, in which N is the number of pollution sources and M is the number of recipients. In our study, we had only one recipient, Beijing. Every element in the matrix represents the contribution from the pollution sources to the recipient's ozone concentration. So when using the S-R matrix, Equation 3 becomes as follows:

$$\sum_{i=1}^{N}\sum_{t=1}^{T_i}\left(u_i * e_{i,t} * a_{i,j} * x_{i,t}\right) \geq S_j \quad \forall j = 1, M \qquad \text{(Equation 5)}$$

where $a_{i,j}$ is the coefficient of sources contributing to the recipient.

2.5 Data and calculation of emission and Cost

2.5.1 Emission data

We adopted the emission sources inventory from the Beijing program, which also includes information of emission reduction technologies and equipments, production scales and yields, to calculate the emission amount of industrial sectors in different years and scenarios. For vehicles and other VOC related sources, we followed Klimont et al. (2002)'s method (as shown in Equation 6), in accordance with the activity level and emission factors of the different emission sources. We used data on vehicle types from the 2007 Beijing Transport Annual Report, and the emission factors from the Vehicle Emission Control Center of Chinese Ministry of Environmental Protection, Hu et al. (2006), and Jing et al. (2006).

$$E_k = \sum_l \sum_m \sum_n A_{k,l,m} ef_{k,l,m} (1 - \eta_{l,m,n} \alpha_{k,l,m,n}) * X_{k,l,m,n}$$

(Equation 6)

Where k denotes districts, l denotes sectors, m denote categories of fuels and production activities, n denotes equipment, E denotes VOCs emissions, A denotes activity level, ef denotes emission factor, η denotes removal efficiency, α denotes maximum usage rate of the equipment, X denotes actual usage rate of the equipment.

2.5.2 Data and calculation of control costs

Technical options

The costs of measures generally include the investment costs (I), fixed operation costs (OM^{fix}) and variable operation costs (OM^{var}). The general cost function of coal power plants (as an example) was used by Cofala and Sanna (1998) in the RAINS model to calculate the cost of NOx abatement measures in Europe (Equation 7). Option cost calculation methods for other technical options are similar, except for the investment costs of construction.

The investments include the expenditure accumulated until the start-up of an installation, such as delivery of the installation, construction, civil works, ducting, engineering and consulting, license fees, land requirement and capital. The model uses investment functions where these cost components are aggregated into one function. The shape of the function is described by its coefficients ci^f and ci^v. The coefficients ci of power plants are given separately for three capacity classes: from 50 to 100 MW, from 100 to 300 MW and above 300 MW. When existing plant is retrofitted with add-on controls (SCR, SNCR) investments are multiplied by a retrofit cost factor. The coefficients of investment functions describe only the costs for construction of the equipment. In order to calculate total investment costs, cost of catalyst is then added (if applicable). Since the lifetime of catalyst is much shorter than the lifetime of the plant, subsequent replacements of catalyst are included in the cost item 'variable operating costs'.

$$I = (ci_1^{f} + \frac{ci_1^{v}}{bs}) + (ci_2^{f} + \frac{ci_2^{v}}{bs}) * (1 + r) + \lambda^{cat} * ci^{cat} \qquad \text{(Equation 7)}$$

Where $ci_1^{f}, ci_1^{v}, ci_2^{f}, ci_2^{v}$: investment function coefficients, cited from the RAINS model; bs: boiler size; λ^{cat}: catalyst volume (per unit of installed capacity); ci^{cat}: unit cost of catalysts; and r: the retrofit cost factor (When existing plant is retrofitted with add-on controls (SCR, SNCR) investments are multiplied by a retrofit cost factor r.)

The investments were annualized over the technical lifetime of plant lt, using the real interest rate q (in percentage) (Equation 8).

$$I^{an} = I * \frac{(1+q)^{lt} * q}{(1+q)^{lt} - 1} \qquad \text{(Equation 8)}$$

The fixed operation cost is a standard percentage of the total investment.

$$OM^{fix} = I * f \qquad \text{(Equation 9)}$$

The variable operation costs were calculated using Equation 10.

$$OM^{\mathrm{var}} = \lambda^e c^e + ef\,\eta\lambda^s c^s \qquad \text{(Equation 10)}$$

Where λ^e: additional electricity demand; c^e: energy price; λ^s: demand for sorbents (materials used to absorb liquids or gases) c^s: price of sorbents; ef: unabated NOx emission factor; and η: removal efficiency.

Non-technical options

The costs of non-technical options encompass policy implementation costs and social costs, which are hard to quantify. If we take, for example, a policy to encourage the reduction of old vehicles and assume that the direct cost of stopping the use of a vehicle is low, this does not mean that car owners will be prepared to give up their cars. If the policy is made mandatory on the other hand, the social costs for car owners may be high and will be hard to quantify. So in such a case, it is best to use subsitution to calculate the policy costs and social costs. We assumed a government subsidy for car owners to eliminate their old cars, the emission status of which cannot even meet China's National Standard I for vehicle emissions (CNSV I, which is the lowest and earliest emission standard). We used the average prices of second-hand (5-8 year old) cars of different types to substitute the willingness to accept (WTA) of the owners of old cars to simulate the cost of this option. Another similar option would be the substitution of traditional oil-paint by water-based paint.

We used boiler size, production capability, coal consumption and other basic information on power plants in Beijing and the surrounding areas as provided by the Beijing Program inventory. Some cost parameters came from the GAINS online model (http://www.iiasa.ac.at/rains/gains-online.html?sb=9) and EPA website. The local electricity prices, coal prices and labour prices in the provinces were used. The quantities of vehicle types, emission factors and annual mileage of the different types of vehicles used were the same as in the emission section. The prices of equipment such as ternary catalyst convertors, fuel truck nozzles, installation fees, and so on, were obtained from the field survey in Beijing, and literatures.

2.6 Identification of feasible control measures

Control Measures for Vehicles

Taking into account the specific operating conditions in Beijing, we analyzed the following policies, requirements and measures.

Limited vehicle use on special roads and at special times: An example would be the driving restriction policies implemented during the Olympic Games in Beijing such as the “Ban on the Last Single or Double Digit of the Vehicle’s License Plate”, “Dedicated Olympic Lanes", and "Traffic Control". However, these measures are not suitable for a long-term use as Davis (2008) showed in his study on Mexico City. As vehicle owners increase their usage of vehicles and motorcycles, or increase the use of high-emission vehicles, and buy more new cars, these policies do no achieve emission reduction effects while incurring high implementation costs. Our study did not include such policies as alternative control measures in Beijing's long-term arrangement.. Instead we included the first and third categories, control on vehicle quantity increase and public transportation.

Strengthening the vehicle emissions inspection and maintenance (I/M) policy in Beijing: According to the I/M policy, vehicles have to be inspected every year by the Transportation Department. If the emission status of a vehicle does not meet the emission standards, it should be equipped with new exhaust gas treatment equipment or it will be declared not road-worthy eliminated mandatorily. At present, China's most important vehicle exhaust gas treatment technology is the three way catalytic converter system, but some old vehicles (that meet CNSV I or CNSV II) have not been installed with ternary catalytic converters. Equipping these old vehicles with ternary catalytic converter systems can help them meet the new emission standards.

Reducing emissions from buses and taxis: Eliminating old buses and taxis and substituting them with clean energy ones, and improving the fuel quality.

Control Measures for Power Plants

NOx control techniques can be categorized as pre-burning period and post-burning period techniques. The first, called the Low NOx Burning (LNB) Techniques, reduces NOx emissions during the coal-burning process. The second is called the Smock Denitrification Technology and reduces emission by acting on the NOx after emission. These techniques are common in NOx control are described below. Low NOx Burning Boilers using the FS technique is the most suitable for most power plant boilers and is implemented most commonly in Beijing. SNCR and SCR have begun to be used, especially for small and medium-scale power plants. As SCR requires a large fixed room, it is more suitable for large-scale power plants. Combining desulfurization and denitrification techniques is still on trial in China, so we will not analyze its implementation in Beijing. LNB, SNCR and SCR are the main techniques considered in our cost study.

As the capacity and age of the power generators are different even in one power plant, NOx control and emission reduction costs may be different. So we analyzed each plant unit and categorized them by production capacity and age (according to year of construction).

Paint use

In developed countries such as the United States and those in Europe or developing metropolises like Beijing, paint and solvent are one of the biggest emission sectors of VOC. However, the paint and solvent industry includes too many sub-industries and sub-sectors, with a variety of control measures. We could not do a complete survey of all these sub-sectors but we did estimate the emission quantities based on a large amount of oil paints used for construction (civilian) and industry (mainly automobile production and renovation). We estimated that water-based paint used in Beijing was currently less than 30%, far less than the 80% used in Europe. As a result, substituting oil-based paint for water-based paint in Beijing will achieve significant VOC emissions reduction.

Gasoline Stations

VOC control options for gasoline stations include three systems: 1) Stage I of the Gasoline Vapor Recovery System (GVRS I) which is fixed to the underground oil tank and pipes connected to the oil tanks; 2) Stage II of the Gasoline Vapor Recovery System (GVRS II) which works on the refueling process by sealing the air circulation system; and 3) the Gasoline Vapor Recovery System for Vehicles (ORVR). However, ORVR is much more expensive than GVRS II which has the same effect of reducing gasoline vapor and spillage.

Beijing has installed and implemented the GVRS I, and since the convening of the Olympic Games, by the end of June 2008, all 1,446 gasoline stations in Beijing completed the installation of GVRS II. As the baseline scenario in our study is based on 2007, the GVRS II is discussed here.

3 Results: Optimization of cost effective control

Conducted the Ambient Least Cost model by all control options indentified in this study, we got the results of optimal route of cost effective control. Figure 1 shows the maximum one-hour mean concentration (MHMC) declining and the marginal average cost increasing as measures/policies are implemented one by one. The marginal average cost is the average annual cost of measures achieving one unit of reduction in ozone concentration. The unit for MHMC is ug/m^3 and the unit for the marginal average cost is million RMB.

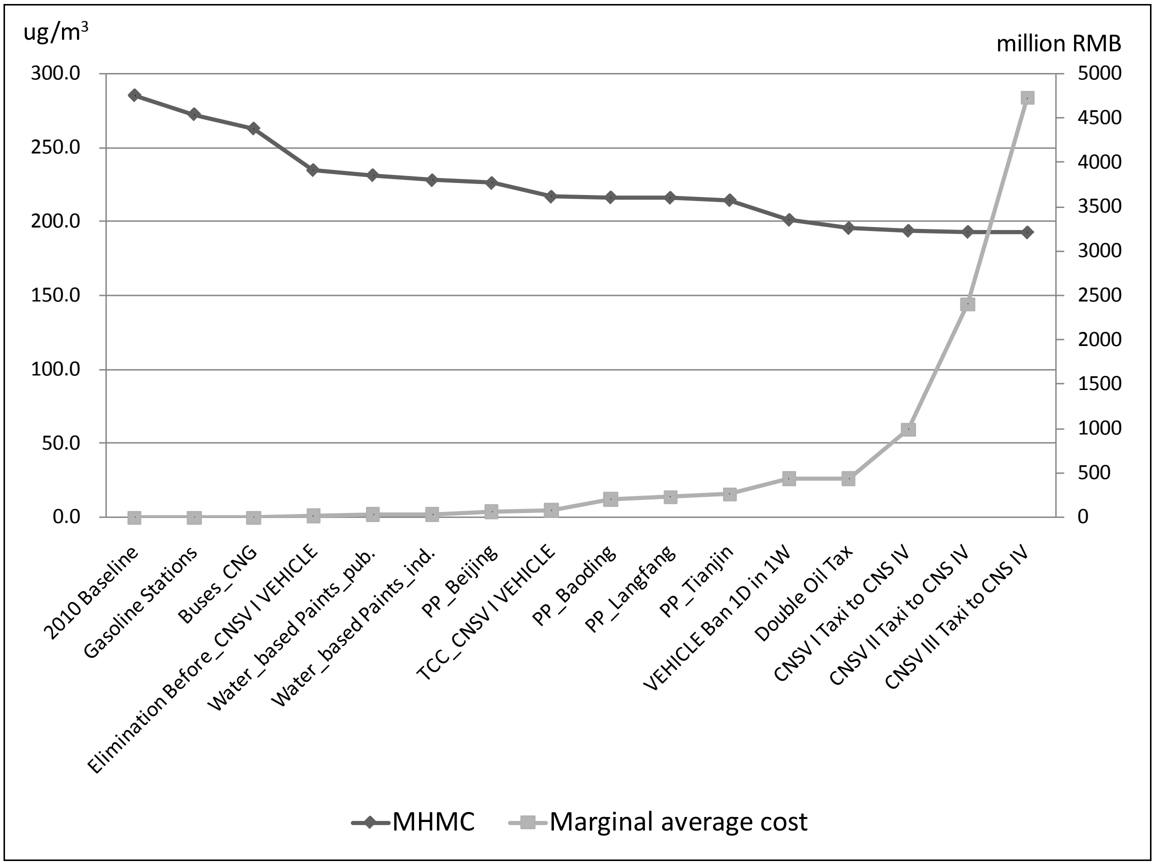


Figure 1 MHMC curve and marginal average cost curve

Notes:

2010 Baseline = Baseline scenario in 2010

Gasoline Stations = Equipping gasoline stations with Stage II Gasoline Vapor Recovery System (GVRS II)

Buses_CNG = Changing normal buses to Compressed Natural Gas (CNG) buses

Elimination Before_CNSV I VEHICLE = Eliminate vehicles where their emission status cannot meet China's National Standard for vehicle emissions (CNSV I)

Water_based Paints_pub. = Public use of water-based paint increases by 20%

Water_based Paints_ind. = Industrial use of water-based paint increases by 20%

PP_Beijing = Adopting different options of LNB, SNCR, SCR and their combinations for different generators with different production capacities in coal power plants in Beijing.

TCC_CNSV I VEHICLE = Installing TCCs or changing old TCCs to new TCCs for vehicles whose emission status meet CNSV I

PP_Baoding = Adopting different options of LNB, SNCR, SCR and their combinations for different generators with different production capacities in coal power plants in Baoding.

PP_Langfang = Adopting different options of LNB, SNCR, SCR and their combinations for different generators with different production capacities in coal power plants in Langfang.

PP_Tianjin = Adopting different options of LNB, SNCR, SCR and their combinations for different generators with different production capacities in coal power plants in Tianjin.

VEHICLE Ban 1D in 1W = Ban on vehicle use one day per week

Double Oil Tax = Doubling the oil tax on all vehicles

CNSV I Taxi to CNS IV = Changing taxis meeting CNSV I emission standards to new taxis meeting CNSV IV standards

CNSV II Taxi to CNS IV = Changing taxis meeting CNSV II emission standards to new taxis meeting CNSV IV standards

CNSV III Taxi to CNS IV = Changing taxis meeting CNSV III emission standards to new taxis meeting CNSV IV standards

The results showed that the Gasoline Vapor Recovery System Stage II (GVRS II) in Beijing's 1,446 gasoline stations was the most cost-effective control measure for ozone reduction in terms of the pollution situation and technical feasibility; followed by the policy to substitute Beijing's gasoline and diesel buses with CNG buses. The 20% increase in water-based paint (replacing oil paints) for civil and industrial use was also found to be cost effective. Among all the measures, those controlling the vehicle sector, such as hastening the elimination of old cars, installing TCCs or changing old TCCs to new ones for vehicles that meet CNSV I emission standards were the most effective options, since vehicles were the largest emitters of NOx and VOC.

Also the cost of controlling vehicles was much less than controlling power plants. There are two main reasons for this. Firstly, most power plants are located out of Beijing, so their ozone concentration effect in Beijing is much less than vehicle emissions in the city. Secondly, the cost of the technology used in power plants was relatively higher. However, the regulation of vehicles carried a higher cost. According to our calculations, a double oil tax for vehicles in Beijing (a market-based policy) would be less cost-effective than a one-day ban per week on car use (a command and control measure). This is contrary to most studies such as Eskeland and Feyzioglu (1995) and Davis (2008) which have found the market-based options more cost-effective than comman and control ones. This is because in our study, the ozone concentration was considered as the only benefit of control measures. If we factor in the full loss of social welfare into the effects of the two policies, the cost-effectiveness results could be different.

In general, in comparing the two biggest sectors i.e., vehicles and power plants, we can see that vehicle control in local Beijing is much more cost-effective than power plants control in the surrounding areas. However, control over power plants in the surrounding areas is also necessary if more air quality improvement is desired.

4 Conclusions

Based on the cost analysis of all measures in different areas and sectors, we applied the Ambient Least Cost Model, and simulated the marginal ozone decline curves and marginal abatement cost curves, by conducting measures/policies individually. Comparing the types of control measures/policies, we found that their cost-effectiveness varied largely by area and sector, influenced by NOx and VOC emission reduction potentials, annual control costs, location (how far from and which direction to Beijing), type of emission sources, and different contribution rates of NOx or VOC. In order to meet certain air quality standards, measures/policies for the different types of emission sources should follow the cost effective order , with the marginal cost increasing, the cost-effective control path should be as follows: (a) Stage II of the Gasoline Vapor Recovery System (GVRS II) used in 1446 Gasoline Stations in Beijing; (b) changing normal buses to CNG buses in Beijing; (c) eliminating old cars (before CNSV I) in Beijing; (d) increasing the use of water-based paints by civil sectors by 20% and (e) by industrial sectors by 20%; (f) installing denitration equipments in Beijing power plants; (g) equipping CNSV I vehicles in Beijing with three-way catalytic convertors (TCC); (h) installing denitration equipments in power plants in Baoding, (i) Langfang, and (j) Tianjin; (k) implementing a Vehicle Ban

One Day Per Week in Beijing; (l) doubling the oil tax in Beijing; (m) substituting CNSV IV taxies for CNSV I, (n) CNSV II, and (o) CNSV III taxies in Beijing.

Vehicles and power plants are the two most potent sectors for ground level ozone control in Beijing. However, measures for vehicles are much more cost effective than measures for power plants. In the short term, eliminating old cars with subsidies or replacing old cars with new cars are good policy strategies. However, in the long term, as new cars with strict emission limits dominate the vehicle market in Beijing, policies aiming at reducing vehicle use frequency should be the main focus. Controlling VOC sources (like gasoline stations and paint use) could be more cost effective than controlling NOx sources, because nowadays most areas in Beijing are VOC dominated areas (ozone concentration is determined by the concentration of VOC in the atmosphere).

Acknowledgement

This study was supported by the Economy and Environment Program for Southeast Asia (EEPSEA), the research program of "Study on Characteristics of Pollutants' Transportation and Reaction in Beijing and Surrounding Areas, and Air Quality Control Strategy", "Campaigns of Air Quality Research in Beijing and Surrounding Regions" of Beijing Science and Technology Commission, and Shanghai Tongji Gao Tingyao Environmental Science and Technology Development Foundation. The authors wish to acknowledge the following for their valuable comments and helps: Dr. Herminia Francisco, Dr. Benoit Laplante, and Ms. Catherine Ndiaye from EEPSEA, Prof. Xu Jintao, Ms. Hu Qian, Mr. Miao Weijie, and members of the Environmental Economics and Policy Study

Group (EEPS) from Peking University; Mr. Tang Dagang and Mr. Yin Hang in the Vehicle Emission Control Center of the Ministry of Environmental Protection of China.

References

Atkinson, S.E. and D.H. Lewis. 1974. A Cost-Effectiveness Analysis of Alternative Air Quality Control Strategies. Journal of Environmental Economics and Management. Vol. 1. 237-250.

Cofala, J.; M. Amann; F. Gyarfas; W. Schoepp; J.C. Boudri; L. Hordijk; C. Kroeze; Li Junfeng; Dai Lin; T.S. Panwar and S. Gupta. 2004. Cost-effective control of SO2 emissions in Asia. Journal of Environmental Management. Vol 72. 149-161.

Davis, L.W. 2008. The Effect of Driving Restrictions on Air Quality in Mexico City. Journal of Political Economy, Vol. 116. No. 1. 38-81.

Ding, A.J., Wang, T., Thouret, V., Cammas, J.P., Nedelec, P., 2008. Tropospheric Ozone Climatology over Beijing: Analysis of Aircraft Data from the MOZAIC Program. Atmospheric Chemistry and Physics. 8, 1-13.

Eskeland, G.S. and T. Feyzioglu. 1995. Rationing Can Backfire: the ‘Day without a Car’ in Mexico City. World Bank. The World Bank Policy Research Working Paper 1554. Washington DC. USA. 40p.

Guariso, G., G. Pirovano and M., Volta, 2004. Multi-objective analysis of ground-level ozone concentration control. Journal of Environmental Management, 71, 25-33.

Hu, J.N.; Hao, J.M.; and Fu, L.X. 2006. Impact of Gas Powered Vehicles on Vehicular Emissions in Beijing. Journal of Tsinghua University (Science and Technology). Vol. 43. No. 3. 350-354. (In Chinese)

Jing, F. and Zhang, X. 2006. Using IVE Model to Analyze Buses Emission. Environmental Science and Technology. Vol. 29. No. 9. 46-48. (In Chinese)

Klimont, Z.; D.G. Streets; S. Gupta; J. Cofala; Fu, L.X. and Y. Ichikawa. Anthropogenic Emissions of Non-Methane Volatile Organic Compounds in China. Atmospheric Environment Vol. 36. 1309-1322.

Krupnick, A.J. and P.R. Portney, 1991. Controlling Urban Air Pollution: A Benefit-Cost Assessment. Science, 252, 522-528.

Krupnick, A., V. McConnell, M. Cannon, T. Stoessell and M. Batz, 2000. Cost-Effective NOx Control in the Eastern United States. RFF working paper.

Li, L.; Hao, J.M. and Hu, J.N. 2005. Analysis and Prediction of Air Quality Influence from Energy Utilization in Beijing. China Environmental Science. Vol. 25. No. 6. 746-750. (In Chinese)

Newell, R.G. and R.N. Stavins, 2003. Cost Heterogeneity and the Potential Savings from Market-Based Policies. Journal of Regulatory Economics, 23 (1), 43-59.

Peking University. 2007. Research on Air Quality Control Strategies for the 29th Olympic Games in Beijing (Surrounding Provinces). Peking University. Research Report. Beijing. China. 241p. (In Chinese)

Shih, J.S., S.M. Bergin, A.J. Krupnick and A.G. Russell, 2003. Controlling Ozone and Fine Particulates: Cost Benefit Analysis with Meteorological Variability. RFF Working Paper.

Streets, D.G., Y.S. Chang, M. Tompkins, Y.S. Ghim and L.D. Carter, 2001. Efficient regional ozone control strategies for the eastern United States. Journal of Environmental Management, 61, 345-365.

Streets, D.G., Fu, J.S., Jang, C.J., Hao, J., He, K., Tang, X., Zhang, Y., Wang, Z., Li, Z., Zhang, Q., Wang, L., Wang, B., Yu, C., 2007. Air Quality During the 2008 Beijing Olympic Games. Atmospheric Environment. 41, 480-492.

Sun, Y., Zhuang, G., Wang, Y., Han, L., Guo, J., Dan, M., Zhang, W., Wang, Z., Hao, Z., 2004. The Air-borne Particulate Pollution in Beijing - Concentration, Composition, Distribution and Sources. Atmospheric Environment. 38, 5991 – 6004.

Tang, X., Li, J., and Chen, D., 1995. Summertime Photochemical Pollution in Beijing, Pure Appl. Chem. 67, 1465-1468.

Wang, X.S., Li, J.L., Zhang, Y.H., Xie, S.D., Tang, X.Y., 2009. Ozone Source Attribution During a Severe Photochemical Smog Episode in Beijing, China. Science in China Series B: Chemistry. 52(8), 1270-1280.

Xu, X., Lin, W., Wang, T., Yan, P., Tang, J., Meng, Z., Wang, Y., 2008. Long-term Trend of Surface Ozone at a Regional Background Station in Eastern China 1991-2006: Enhanced Variability. Atmospheric Chemistry and Physics. 8, 2595-2607.

Environmental Regulations on Eco-Industry with Vertical Oligopolies

Chul-Hi Park and Sang-Ho Lee

Chonnam National University

>Abstract<

This article considers the issue of how clean technology will affect the environmental policy in vertical oligopolies, in which upstream industry produces abatement goods, supported by production subsidy, and downstream industry produces consumption goods emitting pollution, regulated by environmental tax.

We first specify what an optimal pollution tax and abatement subsidy should be when both industries are imperfectly competitive under blockaded entry. We show that optimal pollution tax should be used for negative externality and output restrictions in final production and optimal abatement subsidy should incorporate tax effect on upstream market restrictions in abatement activity. We also examine the relationship between pollution tax and subsidy rate and show that production subsidy for abatement good has the similar form with pollution tax with some weights on each distortion. Therefore, under moderate conditions, the optimal policy has a positive tax on consumption goods and a positive subsidy on abatement goods.

Next, we extend the model to the free entry case in which the number of firms in each market is determined at the zero profit condition endogenously. We then examine the optimality of entry fee and specify what an optimal entry fee should be in both markets under free entry. We show that under moderate conditions, optimal entry fee for both downstream and upstream markets are positive.

Finally we examine the fiscal budget of environmental regulation and show that under the two-part system with entry fee and tax/subsidy regulator's revenue is exactly same with the traditional Pigouvian rate, the amount of marginal damage.

>Notations<

i : The downstream firm i=1.2…n where n : the number of downstream firms
j : The upstream firm j=1.2..m where m : the number of upstream firms
q_i : Polluting good supplied by downstream firms to consumers
$P(Q)$: The inverse demand function of the downstream goods
a_i : abating good demanded by downstream firms
a_j : abating good supplied by upstream firms to downstream firms
r : The price of upstream good
$e(q_i)$: The emission function
$w(a_i)$: The abating function
c_d , c_u : The cost function of each industry
t : The pollution tax
s : The abating subsidy
ϕ_d , ϕ_u : The entry fee or subsidy of each industry

1. Introduction

Recently, the concerns on eco-industry are increasing, in which pollution abatement goods are supplied by a few large providers of abatement technologies. Restrictions in production of abatement goods due to imperfect competition among environmental firms can have a direct negative impact on the environment. In particular, the emergence of this sector under imperfect competition will affect a cost-minimizing decision by the polluting firms and thus, regulation for the eco-industry has then become an important topic for environmental policy to lessen gross emissions.

Traditionally, the basic framework for the environmental taxation on the polluting firms shows that the first-best environmental tax should be chosen equal to the marginal social damage when competition is perfect(Pigou 1920). But when the structure of polluting industry is monopoly, the optimal regulation should be less than the marginal social damage(Buchanan 1969), and this logic of lower optimality could be also applied to the monopoly with abatement technology(Barnett 1980). After that, some works on imperfect competition are extended to the analysis of Cournot oligopoly(Levin 1985; Simpson 1995) and endogenous market structure(Katsoulacos and Xepapadeas 1995; Lee 1999). In sum, Requate(2007) synthesized important works on pollution tax under imperfect competition. All these researches provided the rationale for the second-best of higher/lower optimal tax level, depending upon the relative effects of distortions such as market power, excessive entry, and externality. Therefore, complete internalization of external damages under imperfect competition will impose additional social cost by further restricting the already suboptimal output of the firms and thus, the second-best pollution tax should not be equal to marginal social damage, which does not follow Pigouvian rule.

Alternative framework for environmental taxation on environmental firms was firstly introduced by David and Sinclair-Desgagne(2005). They formulated the vertical oligopolies, in which pollution abatement goods are delivered to polluting firms by environmental firms, and showed that the market power of the eco-industry will bring about higher pollution tax than the marginal social cost of damage. Later, Canton, et al(2008) extended to the vertical Cournot oligopolies, in which downstream industry, producing consumption goods emitting environmental damages, and upstream industry, producing abatement goods to downstream industry, are limited with imperfect competition. And they show that if the tax is the only available instrument used to regulate these distortions, the second-best optimal tax level depends on the market power between eco-industry and polluting industry in the vertical structure.

However, from the viewpoint of policy coordination, it is required to have the exact number of combination of some instruments to remedy different market failures, such as environmental policy for externality, competition policy for imperfect competition, and market structure policy for excessive (or insufficient) entry, as discussed by Schott(2008) and Park and Lee(2009). Therefore, if the government can use a multiple environmental instruments such as tax, subsidy, and entry fee, the first-best optimality could be obtained. In that case, the combination of appropriate policy instruments should be devised. For example, Park and Lee(2009) considered a simple model for polluting oligopolists and proposed a two-part tax system to find the first-best optimum when there are many different market failures. But, they focused on the polluting industry in a partial equilibrium model without considering abatement technology and the impact of eco-industry on environmental policy.

This article considers the existence of eco-industry and its effect on environmental regulation under vertical oligopolies with two industries, in which upstream industry produces abatement goods, supported by production subsidy, and downstream industry produces consumption goods emitting pollution, regulated by environmental tax.

We first specify what an optimal pollution tax and abatement subsidy should be when both industries are imperfectly competitive under blockaded entry. We show that optimal pollution tax should be used for negative externality and output restrictions in final production and optimal abatement subsidy should incorporate tax effect on upstream market restrictions in abatement activity. We also examine the relationship between pollution tax and subsidy rate and show that production subsidy for abatement good has the similar form with pollution tax with some weights on each distortion. Therefore, under moderate conditions, the optimal policy has a positive tax on consumption goods and a positive subsidy on abatement goods.

We next extend the model to the free entry case in which the number of firms in each market is determined at the zero profit condition endogenously. We then provide the optimality of entry fee and specify what an optimal entry fee should be in both markets under free entry. We show that under moderate conditions, optimal entry fee for both downstream and upstream markets are positive.

Finally we examine the fiscal budget of environmental regulation and show that under the multiple instruments regulator's revenue is exactly same with the traditional Pigouvian rate, the amount of marginal damage. Therefore, we show that the policy combination of pollution tax, production subsidy, and entrance fee achieves the first-best optimum for many different market failures financially.

The organization of this paper is as follows: Section 2 constructs the basic model for the vertical structure, consist of polluting firms in downstream industry and environmental firms in upstream industry. In Section 3, we find the optimal environmental tax and abatement subsidy which maximize the social welfare. In the Section 4, we extend the basic model to free entry structure and find the optimal entry fee for each industry to obtain the first-best. The final section provides conclusion.

2. The Basic Model

We consider a vertical industry structure with two oligopolies, in which upstream industry produces abatement goods to downstream industry and downstream industry produces consumption goods to consumers in succession. In that production process, we assume that consumption goods emit negative external effect, called as environmental pollution, which is healed only by abatement goods. Finally, we assume that regulator wants to employ an environmental tax and abatement subsidy.

The following three-stage game is going to be solved by backward induction: (i) Regulator chooses an optimal environmental tax and abatement subsidy to maximize social welfare. (ii) Given abatement subsidy and the demand of abatement goods from downstream firms, upstream industry competes in quantity. (iii) Given environmental tax and the demand of consumption goods from consumers, downstream industry chooses their optimal level of production and abatement.

2.1 Downstream Industry

There are n symmetric downstream firms, indexed by i, where the amount of production of i-th firm is q_i. Each firm's cost function is given by $C_d(q_i)$, where $C_d'(q_i) > 0$ and $C_d''(q_i) \geq 0$. The inverse market demand function of the consumption good is given by $P(Q)$ where $Q = \sum_{i=1}^{n} q_i$ and $P'(Q) < 0.$ However, production activity generates some pollution which is denoted by an emission function, $e(q_i)$. It is identical for all firms and is assumed that $e'(q_i) > 0$ and $e''(q_i) \geq 0$.

The downstream firms are regulated by environmental tax, t, levied on the amount of emission. Thus, each firm has an incentive to reduce the environmental tax by using a clean-up activity which requires some specific abatement goods a_i, sold by upstream firms at a price of r. We assume that downstream firms are price-takers in the eco-industry market. The effectiveness of the abatement goods is given by a function, $w(a_i)$ which measures the amount of pollution cleaned by the purchase of a_i. We assume that this clean-up technology is characterized by a decreasing marginal productivity, i.e., $w'(a_i) > 0$ and $w''(a_i) \leq 0$. That is, more abatement goods consumed decrease the net amount of pollution with a decreasing rate. Then, the net amount of pollution can be defined as $y_i(q_i, a_i) = e(q_i) - w(a_i)$.[1]

Then, any downstream firm wants to maximize the following profit function over the two variables, q_i and a_i, the individual level of the production and the amount of purchased abatement goods, respectively.

$$\max_{q_i, a_i} \Pi_i = P(Q)q_i - C_d(q_i) - r \cdot a_i - t \cdot y_i(q_i, a_i) \cdots\cdots (1)$$

The first-order necessary conditions for Cournot-Nash equilibrium output of consumption goods and consumption of abatement goods are as follows:

$$\frac{\partial \Pi_i}{\partial q_i} = P(Q) + P(Q)'q_i - C_d'(q_i) - t \cdot e'(q_i) = 0 \cdots\cdots (2)$$

$$\frac{\partial \Pi_i}{\partial a_i} = -r - t[-w'(a_i)] = 0 \Rightarrow r = t \cdot w'(a_i) \cdots\cdots (3)$$

Because of the separability of clean-up technology, production decision is separable from abatement decision. In particular, from the equation (3), the abatement activity, a_i is determined as the function of the price of abatement goods, r and environmental tax, t. For instance, the higher environmental tax, the less output production and the more abatement activities.

2.2 Upstream Industry

There are m symmetric upstream firms, indexed by j, where the amount of abatement goods produced by j-th firm is a_j. Each firm's cost function is given by $C_u(a_j)$, where $C_u' > 0$ and $C_u'' \geq 0$. We assume that upstream firms are supported by abatement subsidy based on the sales of abatement goods.

Then, each upstream firm wants to maximize its profit function over the variable a_j, the individual level of the production.

$$\max_{a_j} \Pi_j = r \cdot a_j - C_u(a_j) + s \cdot a_j$$

---

[1] We focus on end-of-pipe pollution abatement, in which abatement activities are additively separable to the production process. This assumption follows David and Sinclair-Desgagne(2005), and Canton et al.(2008).

Since all firms in the upstream industry are able to anticipate the behaviors of downstream firms in (2) and (3), which is separable decision, the upstream firm can anticipate the demand of the abatement goods. So, the profit function of upstream firm can be changed to,

$$\max_{a_j} \Pi_j = t \cdot w'(a_i) \cdot a_j - C_u(a_j) + s \cdot a_j$$

Furthermore, from the assumption that downstream firms are price-takers in the trade, the eco-industry market-clearing price for the abatement goods will be set at $\sum_{i=1}^{n} a_i = \sum_{j=1}^{m} a_j$. That is, $a_i = \frac{1}{n}\sum_{j=1}^{m} a_j$ at symmetric equilibrium in downstream market. Then, the upstream firm's profit function can be changed as follows :

$$\max_{a_j} \Pi = t \cdot w'(\frac{1}{n}\sum_{j=1}^{m} a_j) \cdot a_j - C_u(a_j) + s \cdot a \cdots\cdots(4)$$

The first-order necessary condition for Cournot-Nash equilibrium output of abatement goods can be written as

$$\frac{\partial \Pi_j}{\partial a_j} = t \cdot w'(a_i) + t \cdot w''(a_i)\frac{a_j}{n} - C_u'(a_j) + s = 0 \cdots\cdots(5)$$

Then, the symmetric equilibrium for identical upstream firms, in which $n \cdot a_i = m \cdot a_j$, yields the following condition

$$t\left(w'(\frac{1}{n}\sum_{j=1}^{m} a_j) + w''(\frac{1}{n}\sum_{j=1}^{m} a_j) \cdot \frac{a_j}{n} \right) + s = C_u'(a_j) \cdots\cdots(5')$$

From the equation (5'), the decision of abatement production is determined by the shape of the clean-up technology, the marginal cost of producing abatement goods, the number of firms in both upstream and downstream industries, and the regulator's two instruments, abatement subsidy, s and environmental tax, t. Therefore, if others are being equal, more abatement goods will be produced when (i) environmental tax or abatement subsidy is higher, (ii) clean-up technology is more efficient, (iii) the number of firms in upstream market is larger, (iv) the number of firms in downstream market is smaller, and (iii) eco-industry production technology is efficient.

3. Optimal Tax and Subsidy

Let $D(Y)$ denote environmental damages from pollution, where $D'(Y) > 0, D''(Y) \geq 0$ and $Y = n \cdot y_i$. Then, the social welfare is defined as the sum of consumers' and producers' surplus less the environmental damages in (6).

The regulator's problem is to choose the levels of output of consumption and abatement goods, maximizing the following social welfare function, where $Q = nq_i$ and $A = na_i = ma_j$ at the symmetric equilibrium:

$$\max_{q_i, a_j} W = \int_0^{nq_i} P(u)du - n \cdot C_d(q_i) - m \cdot C_u(a_j) - D(Y) \cdots\cdots (6)$$

The first-order necessary conditions for interior solutions can be written for the optimal allocation as follows:

$$\frac{\partial W}{\partial q_i} = n\left(P(Q) - C_d'(q_i) - D'(Y) \cdot e'(q_i)\right) = 0 \cdots\cdots (7)$$

$$\frac{\partial W}{\partial a_j} = m\left(-C_u'(a_j) + D'(Y) \cdot w'(\frac{m}{n} a_j)\right) = 0 \cdots\cdots (8)$$

Using market equilibrium conditions in equation (2) and optimality conditions in (7), we have the optimal environmental tax:

$$t = D'(Y) + \frac{P'(Q)q_i}{e'(q_i)} = D'(Y) + \frac{P'(Q)Q}{ne'(q_i)} \cdots\cdots (9)$$

That is, if the regulator imposes an emission tax in (9) to downstream polluting firms, each firm produces the social optimum production in (7). Then, the optimal environmental tax in (9) is the sum of distortion from environmental damages and distortion from downstream firm's market power per marginal emission. As we can see, the first term of environmental distortion is positive and the second term of market distortion is negative. Therefore, the environmental tax could be either positive or negative, depending on the relative size of the distortions from environmental damages and downstream firm's market power, where a negative value for the environmental tax would correspond to a subsidy.[2] Notice that when competition is perfect, i.e., $n \to \infty$, the optimal tax is the exact same with the social marginal damage.
Similarly, using market equilibrium conditions in equation (5) and optimality conditions in (8), we have the optimal environmental abatement subsidy:

$$s = D'(Y)w'(a_i) - t\left(w'(a_i) + w''(a_i)\frac{a_i}{m}\right) \cdots\cdots (10)$$

That is, if the regulator imposes a production subsidy in (10) to downstream polluting firms, each firm produces the social optimum production in (8), we have the following optimal abatement subsidy:

$$s = -\left(D'(Y) + \frac{P'(Q)q_i}{e'(q_i)}\right)w''(a_i)\frac{a_i}{m} - \frac{P'(Q)q_i}{e'(q_i)}w'(a_i) \cdots\cdots (10')$$

$$= D'(Y)w'(a_i)\frac{\varepsilon_{w'}}{m} - \frac{P'(Q)q_i}{e'(q_i)}w'(a_i)\left(\frac{m - \varepsilon_{w'}}{m}\right) \cdots\cdots (10'')$$

where $\varepsilon_{w'} = -\frac{w''(a_i)}{w'(a_i)}a_i > 0$, which indicates the relative concavity of abatement function.

A few remarks are in order. First, the optimal abatement subsidy in (10") is also the combination of two distortions, environmental damages and downstream firm's market power, with some weights on each distortion. It implies that the optimal abatement subsidy is closely related with optimal environmental tax in (9). For example, if t is zero, $s = D'(Y)w'(a_i)$, which is positive.

---

[2] On this point, see Shaffer (1995) and Lee(1999) with oligopolies under blockaded entry.

In particular, if t is nonnegative, s is always positive from (10'). Therefore, under moderate conditions where environmental damage effect is big enough, i.e., $D'(Y) \geq -P'(Q)q_i / e'(q_i)$, the optimal condition requires a positive tax on downstream firms and a positive subsidy on upstream firms.

However, if market distortion effect is big enough, i.e., $D'(Y) < -P'(Q)q_i / e'(q_i)$, the optimal environmental tax is negative. For example, if $t = D'w' /(w' + w'' \frac{a_i}{m})$, from (10"), the optimal subsidy will be zero. Alternatively, from (9), the optimal tax should be $t = mP'q_i / e'\varepsilon_{w'}$, which is negative, or $\varepsilon_{w'} = k \equiv \frac{mP'(Q)q_i / e'(q_i)}{D'(Y) + P'(Q)q_i / e'(q_i)}$, where k is greater than m, to get zero subsidy at the optimum. Thus, the subsidies on both industries are necessary only when $\varepsilon_{w'} < k$. Therefore, when the concavity of abatement function is not too weak, i.e., the value of $\varepsilon_{w'}$ is smaller than or equal to m ($0 < \varepsilon_{w'} \leq m$), then abatement subsidy is always positive. But if the value of $\varepsilon_{w'}$ is greater than m ($\varepsilon_{w'} > m$) and thus the concavity of abatement function is too weak, then the abatement subsidy could be either positive or negative, depending on the relative size of $\varepsilon_{w'}$ and k. [3]

Second, when downstream market is perfect competition, the optimal tax is positive, $t = D'$ and the optimal subsidy is also positive, $s = -D'w''a_i / m$. Notice that this subsidy decreases as the number of environmental firms increases. In particular, when upstream market is perfect competition, i.e, $m \to \infty$, the optimal subsidy is zero.

Finally, let us examine government revenue calculated as the sum of taxes less subsidies:

$$R^B = nty_i - msa_j$$
$$= D'(Y)\left[Y + w''(a_i)a_i a_j\right] + \frac{P'(Q)q_i}{e'(q_i)}\left[Y + w''(a_i)a_i a_j + mw'(a_i)a_j\right]$$

Government revenue is also composed of the two distortions, environmental damages and downstream firm's market power, with some weights on each distortion. Therefore, government revenue could be either positive or negative, depending on the relative size of the relative concavity of abatement function. If the government revenue is negative, the government faces financial budget problem from employing environmental tax and abatement subsidy.

4. Extension to Free Entry

In many industries under imperfect competition barriers to entry are not sufficiently high. For instance, if a large number of entrants exist, entry into the market cannot be controllable as a fixed number. Therefore, we relax the assumption of blockaded entry and consider an industry equilibrium where the output of individual firm and the number of firms in the industry are both endogenously determined by free entry and exit, in which the equilibrium number of firms is endogenously determined by the zero-profit condition.[4]

---

[3] From the second-order sufficient conditions, only when the concavity of abatement function is not too weak, there exists a unique m-firm Cournot-Nash equilibrium in the eco-industry market. On this point, see Canton et al.(2008)

[4] This issue is related to the analysis of endogenous market structure. For more discussion on endogenous market structure with free entry, see Shaffer(1995), Katsoulacos and Xepapadeas (1995), and Lee(1999).

The regulator could attempt to permit entry into an industry and to find appropriative instruments. In particular, we consider the two-part system, the combined form of output tax/subsidy and entry fee. By denoting ϕ_d as entry fee for downstream firm and ϕ_u as entry fee for upstream firm, we can get the following zero-profit conditions of each industry.

$$\Pi_i = P(Q)q_i - C_d(q_i) - r \cdot a_i - t \cdot y_i - \phi_d = 0 \cdots\cdots (11)$$
$$\Pi_j = r \cdot a_j - C_u(a_j) + s \cdot a - \phi_u = 0 \cdots\cdots (12)$$

From the equilibrium condition in (3), and optimal environmental tax in (9), we have the following zero profit condition for downstream market:

$$\Pi_i = P(Q)q_i - C_d(q_i) - \left(D'(Q) + \frac{P'(Q)q_i}{e'(q_i)} \right) [y_i + w'(a_i)] - \phi_d = 0 \cdots\cdots (11')$$

Similarly, from the equilibrium condition in (5), and optimal abatement subsidy in (10), we have the following zero profit condition for upstream market:

$$\Pi_j = D'(Y)w'(a_i)a_j - C_u(a_j) - \left(D'(Y) + \frac{P'(Q)q_i}{e'(q_i)} \right) w''(a_i) \frac{a_i a_j}{m} - \phi_u = 0 \cdots\cdots (12')$$

On the other hand, from the social welfare function in (6), we can derive the following first-order necessary conditions over the two variables, n and m, the number of firms in each industry:

$$\frac{\partial W}{\partial n} = P(Q)q_i - C_d(q_i) - D'(Y)[y_i + w'(a_i)a_i] = 0 \cdots\cdots (13)$$
$$\frac{\partial W}{\partial m} = -C_u(a_j) + D'(Y)w'(a_i)a_j = 0 \cdots\cdots (14)$$

Then, using market equilibrium conditions and optimality conditions in (11) and (13), and (12) and (14), the following optimal entry fee of each industry could be obtained:

$$\phi_d = -\frac{P'(Q)Q}{ne'(q_i)} [y_i + w'(a_i)a_i] \cdots\cdots (15)$$
$$\phi_u = -\left(D'(Y) + \frac{P'(Q)}{e'(q_i)} q_i \right) w''(a_i) \frac{a_i a_j}{m} = -tw''(a_i) \frac{a_i a_j}{m} \cdots\cdots (16)$$

A few remarks are in order. First, from (15), the entry fee of downstream firm is always positive. And it approaches to zero when the market is perfect competition.

Second, from (16), the entry fee of upstream firms has similar form with environmental tax with some weights. Therefore, when the optimal environmental tax for downstream firms is negative, which is subsidy, the entry fee of upstream firms is also negative, which actually means entry subsidy of upstream firms.

Third, the entry fee of upstream firms depends on the number of firms in both downstream and upstream industries. For example, as $n \to \infty$, where downstream market is perfect competition, the optimal emission tax is positive, $t = D'$ and thus, the entry fee of upstream firms is also positive. But, the entry fee of upstream firms is decreasing as m is increasing. In particular, as

Schott(2008) compares several different environmental policy instruments, and Park and Lee(2010) suggest two-part system of entry fee and emission tax to achieve the first-best.

$m \to \infty$, where upstream market is perfect competition, it approaches to zero.
Fourth, total payment of a downstream firm is as follows:

$$\phi_d + ty_i = D'(Y)y_i - \frac{P'(Q)q_i}{e'(q_i)} w'(a_i)a_i$$

The total payment of a downstream firm captures not only environmental damage effect but output distortion effect from downstream firm's market power with some weights.
Fifth, , total payment of a upstream firm is as follows:

$$\phi_u - sa_j = \frac{P'(Q)q_i}{e'(q_i)} w'(a_i)a_j$$

Total payment of a upstream firm captures output distortion effect from downstream firm's market power with the same weights on the payment of a downstream firm, which will be cancelled out in an aggregated payment.
Finally, as an aggregation, the government revenue can be calculated as the sum of taxes less subsidies. Then, the regulator can raise the following revenues from the regulation.

$$R^F = n\left[\phi_d + ty_i\right] + m\left[\phi_u - sa_j\right] = n\left[e(q_i) - w(a_i)\right]D'(Y) = D'(Y)Y \cdots\cdots (19)$$

Notice that the government revenue is always positive and is exactly same with the Pigouvian tax rate. Therefore, this regulation is financially feasible from the standpoint of regulator. In addition, if environmental damages can be covered by the revenue, i.e., $R(Y) > D(Y)$ or $D'(Y) > \frac{D(Y)}{Y}$, the regulator doesn't need to construct the second-best Ramsey rule, in which the budget balance of regulation should be taken into policy consideration.[5]

5. Concluding Remarks

This article analyzed the relationship between clean technology management and environmental policy in a vertical oligopoly structure, and conveyed the message that imperfect competition among upstream environmental firms and downstream polluting firms does matter for environmental regulation. In particular, we employed the appropriate combination of policy instruments such as emission tax, production subsidy, and entry fee to correct simultaneously for the pollution externality, output distortion, and excessive (or insufficient) entry.
The followings are the main findings: First, we considered an optimal pollution tax and abatement subsidy when both upstream and downstream industries are imperfectly competitive under blockaded entry, and shown that optimal pollution tax should be used for negative externality and output restrictions in final production and optimal abatement subsidy should incorporate tax effect on upstream market restrictions in abatement activity.
Second, we examined the relationship between pollution tax and subsidy rate and shown that production subsidy for abatement good has the similar form with pollution tax with some weights on each distortion. Therefore, under moderate conditions, the optimal policy has a positive tax on consumption goods and a positive subsidy on abatement goods.
Third, we extended the model to the free entry case for both industries and provided optimal two-part system with entry fee. In particular, we shown that under moderate conditions, optimal entry fee for both downstream and upstream markets are positive. Furthermore, we shown that regulator's revenue is exactly same with the traditional Pigouvian rate, the amount of marginal damage.

---

[5] For the feasibility of financial budget, see Shaffer(1995) and Sugeta and Matsumoto(2005)

However, political constraints such as public opinion or industrial lobbies and administrative costs for designing optimal policy may leave regulator with an incomplete set of instruments to choose from. Moreover, policy coordination between various regulators in different government bodies such as environmental protection and antitrust agencies deserves closer scrutiny.

References

Barnett, A.H., (1980), "The Pigouvian tax rule under monopoly", *American Economic Review* 70, pp. 1037–1041.

Buchanan, J.M., (1969), "External deseconomies, corrective taxes and market structures", *American Economic Review* 59, pp. 174–177.

Canton, J. and A. Soubeyran . and H. Stahn (2008), "Environmental Taxation and Vertical Cournot Oligopolies: How Eco-industries Matter", *Environmental and Resource Economics* 40, pp. 369-382.

David, M. and B, Sinclair-Desgagne, (2005), "Environmental Regulation and the Eco-Industry", *Journal of Regulatory Economics*; 28:2 pp. 141–155.

Katsoulacos, Y. and A. Xepapadeas, (1995), "Environmental Policy under Oligopoly with Endogenous Market Structure", *Scandinavian Journal of Economics* 97, pp. 411–420.

Lee, S.H., (1999), "Optimal Taxation for Polluting Oligopolists with Endogenous Market Structure", *Journal of Regulatory Economics* 15, pp. 293-308.

Levin, D., (1985), "Taxation within Cournot oligopoly", *Journal of Public Economics* 27, pp. 281–290.

Park, C.H. and S.H. Lee, (2010), "Free Entry and Pigouvian Tax for Polluting Oligopolists", working paper, Chonnam National University.

Pigou A.C., (1920), "The economics of welfare", Macmillan, London.

Requate, T. (2007), "Environmental Policy under Imperfect Competition" In T. tietenberg and H. Folmer (eds) The International Yeabook of Environmental and Resource Economics 2006/2007. Northampton, MA: Edward Elgar.

Schott, S., (2008), "Regulatory Coordination and Optimal Taxation of Polluters in Non-Competitive Markets." working paper, Carleton University.

Shaffer, S. (1995), "Optimal Linear Taxation of Polluting Oligopolists", *Journal of Regulatory Economics* 7, pp. 85-100 .

Simpson, R., (1995), "Optimal pollution tax in a Cournot duopoly", *Environmental and Resource Economics* 6, pp. 359–369

Sugeta, H. and S. Matsumoto, (2005), "Green Tax Reform in an Oligopolistic Industry", *Environmental and Resource Economics* 31, pp. 253-274.

Cost Efficiency of Four Emission-Reducing Instruments: Price, Quantity, Hybrid, and General Indexed Quantity

Hsiao-Chi Chen and Shi-Miin Liu*

June 2010

Abstract

This paper investigates cost efficiency of four emission-reducing instruments: price, quantity, hybrid, and general indexed quantity. A two-stage game is constructed for each policy instrument, and corresponding equilibria are derived. By comparing these equilibria, relative cost efficiency of the instruments can be acquired. We discover that the general indexed quantity instrument is preferred when the slope of marginal damage of emissions exceeds that of marginal abatement cost of emissions, or when correlation between cost shock and index variable is high enough. For the rest cases, price instrument is preferred. However, if price control is not politically feasible, either hybrid or general indexed quantity policy is preferred.

Keywords: Cost efficiency, general indexed quantity, hybrid, price, quantity.

*The authors are professors in the Department of Economics at National Taipei University, Taipei County 23741, Taiwan, ROC. The corresponding author is Hsiao-Chi Chen with e-mail address hchen@mail.ntpu.edu.tw.

1. Introduction

In current literature on reducing pollutant emissions, four instruments often mentioned and investigated are price, quantity, hybrid, and general indexed quantity. Under no uncertainty, we know that price and quantity policies are equivalent. However, this may not be true when benefit or cost uncertainties appear. In a pioneer work, Weitzman (1974) explores the superiority of regulator's price and quantity controls over a monopoly firm under uncertainty. He demonstrates that price control is better if firm's marginal production cost is steeper than its marginal benefit. Otherwise, quantity control is better.

By regarding emission tax as price control and emission trading (or emission cap) as quantity control, the outcomes of Weitzman (1974, 1978) can be used to compare relative advantage of emission tax and emission trading. However, Pizer (2002) shows that emission tax may lead to firm's high compliance cost, and Cline (2004) illustrates that firms may suffer from high price volatility under emission trading. Thus, a hybrid or safety valve policy is considered. Under safety valve policy, an emission cap is set through free emission permit distribution, and firms are allowed to buy unlimited permits from the regulator at a predetermined (trigger) price. Pizer (2002) and Jacoby and Ellerman (2004) show that hybrid policy could perform better than a pure instrument policy. On the other hand, Newell and Pizer (2008) propose general indexed quantity policy, in which firm's emission limit is a linear function of a random index variable such as GDP. They also show that general indexed quantity may be preferred to both price and quantity instruments. Webster et al. (2010) compare hybrid and general indexed quantity, and find that the latter is better when correlation between cost uncertainty and index variable is high enough. The above studies discuss only two or three of the policy instruments once. If all four instruments are feasible, which would perform better is certainly an interesting question. This paper thus tries to answer the question from the cost-effectiveness viewpoint of these policy instruments.

We build a two-stage game for each instrument. Except Weitzman (1974) and Roberts and Spence (1976), other works mentioned above ignore interactions between firms and the regulator. If markets are perfectly competitive, considering the interactions or not would make no big difference. However, including these interactions are critical when examining policy instruments under imperfectly competitive markets. Associated subgame perfect equilibria of the four setups are derived and corresponding equilibrium expected social costs are compared. We find that the equilibrium expected social cost of hybrid policy is within those of price and quantity policies. Accordingly, we can compare the equilibrium costs of price, quantity, and general indexed quantity policies to uncover the instruments with the lowest cost. It is discovered that general indexed quantity is preferred when the slope of marginal damage of emissions is steeper than that of marginal abatement cost of emissions, or when corelation of cost shock and index variable is high. These outcomes are similar to Newell and Pizer's (2008). However, when price control is not politically feasible, such as in the USA, either hybrid or general indexed quantity policy is preferred. This result extends the finding of Webster et al. (2010).

This paper is organized as follows. The model is presented in Section 2. Equilibria of these policy instruments are derived in Section 3, and compared in Section 4. Finally, the conclusions are drawn in Section 5.

2. The Model

Denote e a firm's pollutant emissions. Following Weitzman (1974), we adopt the ensuing quadratic functions of abatement cost and damage of emissions.

$$C(e,\ \epsilon) = c_0 - c_1 e + \frac{c_2}{2}e^2 - \epsilon e, \text{ and} \tag{1}$$

$$D(e) = d_0 + d_1 e + \frac{d_2}{2}e^2, \tag{2}$$

where $c_i,\ d_i,\ i = 0,\ 1,\ 2,$ are positive parameters, and ϵ represents cost shock with zero mean and variance σ_ϵ^2. Including another random variable in the damage function, which is independent of ϵ, will not alter our outcomes. Positive ϵ will reduce firm's abatement cost, while negative ϵ will raise it. Denote $f(\epsilon)$ the probability density function (pdf) of ϵ over the range $[-\underline{\epsilon},\ \underline{\epsilon}]$ with $\underline{\epsilon} > 0$. Equations (1)-(2) imply that the abatement cost and damage functions are strictly convex, and have linear marginal abatement cost and marginal damage as follows.

$$C'(e,\ \epsilon) = -c_1 + c_2 e - \epsilon, \text{ and} \tag{3}$$

$$D'(e) = d_1 + d_2 e. \tag{4}$$

Here we have $D'(e) > 0$, meaning that the damage will increase with firm's rising emissions. On the other hand, it is plausible to assume that $C'(e,\ \epsilon) < 0$ for all e and ϵ because firm's abatement cost should decrease with its rising emissions.[1] Moreover, to make the optimal emission exist, we need the condition of $-C'(0,\ \epsilon) > D'(0)$ for all e and ϵ. Therefore, $c_1 - \underline{\epsilon} > d_1$ is assumed.

The regulator can employ four instruments to reduce pollutant emissions: emission tax (price control), emission cap (quantity control), safety valve (hybrid control), and general indexed quantity. For each policy, we construct a two-stage game to characterize interactions between the regulator and the firm. The associated subgame perfect equilibria (hereafter SPE) and regulator's equilibrium expected social costs are derived in the following.

3. Four Equilibrium Policies

3.1. Equilibrium Emission Tax

Using this instrument, the regulator first announces an emission tax, t^*, to minimize the expected social cost

$$SC \equiv D(e) + EC(e,\ \epsilon), \tag{5}$$

[1] Under the condition of large c_1 with $c_1 > c_2 e_b + \underline{\epsilon}$, we will have $C'(e,\ \epsilon) < 0$ for all e and ϵ, where e_b is firm's emission level under no abatement.

where E is the expectation operator taken over ϵ. Then, a value of cost shock (ϵ) is realized and revealed to the firm. In the second stage, given t^* and ϵ, the firm chooses optimal emission level e_t^* to minimize its total cost

$$TC_t \equiv C(e,\ \epsilon) + te. \tag{6}$$

By backward induction, we can obtain the following SPE, $(t^*,\ e_t^*)$.

Proposition 1. *The equilibrium price control policy is* $(t^* = \frac{c_1 d_2 + c_2 d_1}{c_2 + d_2},\ e_t^* = \frac{c_1 + \epsilon - t^*}{c_2})$. *At equilibrium, the regulator's expected social cost is*

$$SC_p^* = c_0 + d_0 + (d_1 - c_1)\bar{e}^* + \frac{(c_2 + d_2)}{2}(\bar{e}^*)^2 + \frac{(d_2 - c_2)}{2c_2^2}\sigma_\epsilon^2, \tag{7}$$

where $\bar{e}^* = \frac{c_1 - d_1}{c_2 + d_2} > 0$.

Proof. See the Appendix.

At optimal emission level, firm's marginal cost of emissions $(-C'(e_t^*,\ \epsilon))$ equals the emission tax (t^*). And at optimal emission tax, marginal damage of emissions $(D'(e_t^*))$ equals the expected marginal cost of emissions $(-EC'(e_t^*,\ \epsilon))$.

3.2. Equilibrium Emission Cap

Using this instrument, the regulator first announces an emission cap, $\bar{e}_q^*$, to minimize the expected social cost defined in (5). Then, a value of cost shock is realized and revealed to the firm. In the second stage, given $\bar{e}_q^*$ and ϵ, the firm chooses emission level e_q^* to solve the problem of

$$\min_e\ C(e,\ \epsilon) \quad \text{s.t.} \quad e \le \bar{e}_q^*. \tag{8}$$

Again, by backward induction, we can get the ensuing SPE, $(\bar{e}_q^*,\ e_q^*)$.

Proposition 2. *The equilibrium quantity control policy is* $(\bar{e}_q^* = \bar{e}^*,\ e_q^* = \bar{e}_q^*)$. *At equilibrium, the regulator's expected social cost is*

$$SC_q^* = c_0 + d_0 + (d_1 - c_1)\bar{e}^* + \frac{(c_2 + d_2)}{2}(\bar{e}^*)^2, \tag{9}$$

where $\bar{e}^* = \frac{c_1 - d_1}{c_2 + d_2} > 0$.

Proof. See the Appendix.

Since the firm's abatement cost will decrease with its rising emissions, it is optimal for her to discharge as many emissions as possible. Thus, the emission constraint will bind. And the regulator will set an emission cap at which marginal damage of emissions equals firm's expected marginal cost of emissions.

3.3. Equilibrium Hybrid Instrument

Adopting this policy, the regulator first announces $(\bar{e}_h^*,\ p_s^*)$, where $\bar{e}_h^*$ is a trading quantity limit and p_s^* is a trigger price at which the firm can buy unlimited amount when its emission level exceeds $\bar{e}_h^*$. This hybrid policy minimizes the expected social cost defined in (5). Then, a value of cost uncertainty is realized and observed by the firm. In the second period, given $(\bar{e}_h^*,\ p_s^*)$ and ϵ, the firm chooses emission level e_h^* to minimize its total cost

$$FC = \begin{cases} C(e,\ \epsilon) & \text{if } e \leq \bar{e}_h^*, \\ C(e,\ \epsilon) + p_s^*(e - \bar{e}) & \text{if } e > \bar{e}_h^*. \end{cases} \tag{10}$$

By backward induction, we can derive the SPE, $\{(\bar{e}_h^*,\ p_s^*),\ e_h^*\}$, below.

Proposition 3. *The equilibrium hybrid policy is* $\{(\bar{e}_h^* = \bar{e}^*,\ p_s^* = \frac{c_1 d_2 + c_2 d_1}{c_2 + d_2} > 0),\ (e_h^* = \bar{e}^*$ *if* $\epsilon < 0$, *and* $e_h^* = \frac{c_1 + \epsilon - p_s^*}{c_2}$ *if* $\epsilon > 0)\}$. *At equilibrium, the regulator's expected social cost is*

$$SC_h^* = c_0 + d_0 + (d_1 - c_1)\bar{e}^* + \frac{(c_2 + d_2)}{2}(\bar{e}^*)^2 + \frac{(d_2 - c_2)}{2c_2^2}E(\epsilon^2 |\ \epsilon > 0), \tag{11}$$

where $\bar{e}^* = \frac{c_1 - d_1}{c_2 + d_2} > 0$ *and* $E(\epsilon^2 |\ \epsilon > 0) = \int_0^{\bar{\epsilon}} \epsilon^2 f(\epsilon) d\epsilon$ *being the variation of positive cost shocks.*

Proof. See the Appendix.

The intuition of Proposition 3 is as follows. For negative cost shocks, the firm's marginal cost of emissions, $-C'(e,\ \epsilon)$, increases with rising magnitudes of cost shocks.

Accordingly, the firm has no incentive to discharge an amount greater than the given emission cap. In contrast, for positive cost shocks, the firm's marginal cost of emissions, $-C'(e,\ \epsilon)$, decreases with rising magnitudes of cost shocks. Thus, the firm has incentive to discharge an amount larger than the given emission cap if the trigger price is low enough. Given the firm's optimal behavior just described, the regulator will set an emission cap at which the marginal damage of emissions ($\frac{\partial D}{\partial e} = d_1 + d_2\bar{e}^*$) equals the expected marginal cost of emissions ($-\frac{\partial EC}{\partial e} = c_1 - c_2\bar{e}^*$). And the equilibrium trigger price will be selected to equal the expected marginal cost of optimal emission, i.e., $p_s^* = -\frac{\partial EC(e_h^*,\ \epsilon)}{\partial e}$. Moreover, this trigger price will be smaller than the firm's expected marginal cost at the emission limit, i.e., $p_s^* < -\frac{\partial EC(\bar{e}^*,\ \epsilon)}{\partial e}$.

Webster et al. (2010) investigate hybrid policy, but interactions between the regulator and the firm are ignored. Thus, probability of the trigger price being activated is ad hoc and exogenous. Since our model considers players' strategic behavior, probability of the trigger price being activated is exactly the probability of having positive cost shocks.

3.4. Equilibrium General Indexed Quantity

In this section, we analyze general indexed quantity policy studied by both Newell and Pizer (2008) and Webster et al. (2010). Under the circumstance, the regulator chooses emission limit $\bar{e}$ as a linear function of another exogenous variable x, such as GDP. That is,

$$\bar{e}(x) = a + rx,$$

where a and r are policy design variables and $E(x) = \bar{x}$, $V(x) = \sigma_x^2$, and $Cov(x,\ \epsilon) = \sigma_{x\epsilon}$.

A two-stage game proceeds as follows. First, the regulator announces $(a^*,\ r^*)$, which minimizes the expected social cost defined in (5). Then, a pair random variable

$(\epsilon,\ x)$ is realized and observed by the firm. In the second period, given $(a^*,\ r^*)$ and $(\epsilon,\ x)$, the firm chooses emission level e_I^* to minimize its total cost defined in (8) but with $\bar{e}_q^*$ replaced with $(a^* + r^*x)$. By backward induction, we can obtain the SPE, $\{(a^*,\ r^*),\ e_I^*\}$, below.

Proposition 4. *The equilibrium general indexed quantity policy is* $\{(a^* = \frac{(c_1-d_1)\sigma_x^2 - \bar{x}\sigma_{x\epsilon}}{(c_2+d_2)\sigma_x^2},$ $r^* = \frac{\sigma_{x\epsilon}}{(c_2+d_2)\sigma_x^2}),\ e_I^* = a^* + r^*x\}$. *At equilibrium, the regulator's expected social cost is*

$$SC_I^* = c_0 + d_0 + (d_1 - c_1)\bar{e}^* + \frac{(c_2 + d_2)}{2}(\bar{e}^*)^2 - \frac{\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2}, \tag{12}$$

where $\bar{e}^* = \frac{c_1-d_1}{c_2+d_2} > 0$. *Proof.* See the Appendix.

As in Newell and Pizer (2008), the higher correlation between x and ϵ is, the lower equilibrium expected social cost is. For instance, high correlation between GDP and cost shock allows the regulator to extract more information about cost shocks from the GDP data. Thus, the regulator can design a policy closer to the first-best one, and distortion caused by cost uncertainty will vanish.

4. Cost Efficiency of These Instruments

First, we compare cost efficiency of three instruments, i.e., price, quantity, and hybrid. By (7) and (9), we have

$$SC_p^* - SC_q^* = \frac{(d_2 - c_2)\sigma_\epsilon^2}{2c_2^2} \geq\ (\leq)\ 0 \text{ iff } \ d_2 \geq\ (\leq)\ c_2. \tag{13}$$

This outcome is similar to Weitzman's (1974). That is, relative efficiency of price and quantity instruments is completely determined by relative slopes of marginal damage of emissions and marginal abatement cost of emissions. When the slope of marginal damage of emissions is bigger, price instrument is preferred to quantity. In the opposite, quantity instrument is preferred.

Next, by (9) and (11), we have

$$SC_h^* - SC_q^* = \frac{(d_2 - c_2)}{2c_2^2}E(\epsilon^2 \mid \epsilon > 0) \geq\ (\leq)\ 0 \text{ iff } \ d_2 \geq\ (\leq)\ c_2. \tag{14}$$

It means that relative efficiency of hybrid and quantity instruments also depends on relative slopes of marginal damage of emissions and marginal abatement cost of emissions. Finally, by (7) and (11), we have

$$SC_h^* - SC_p^* = \frac{(d_2 - c_2)}{2c_2^2}[E(\epsilon^2 \mid \epsilon > 0) - \sigma_\epsilon^2] \geq \ (\leq)\ 0 \text{ iff } \ d_2 \leq \ (\geq)\ c_2 \tag{15}$$

because the variation degree of positive cost shocks is less than that of cost shocks in the whole range. Still, equation (15) implies that relative cost efficiency of hybrid and price instruments is completely determined by relative slopes of marginal damage of emissions and marginal abatement cost of emissions. Thus, if $d_2 \geq c_2$, equations (13)-(15) suggest

$$SC_q^* \leq SC_h^* \leq SC_p^*, \tag{16}$$

meaning that quantity instrument is preferred. In contrast, if $d_2 \leq c_2$, equations (13)-(15) imply

$$SC_p^* \leq SC_h^* \leq SC_q^*, \tag{17}$$

meaning that price instrument is preferred. The outcomes of (16)-(17) are summarized below.

Proposition 5. *Suppose that the regulator considers only instruments of price, quantity, and hybrid in reducing pollutant emissions. Then, if $d_2 \geq c_2$, quantity is preferred to both price and hybrid instruments. In contrast, if $d_2 \leq c_2$, price is preferred to both quantity and hybrid instruments.*

As shown in Propositions 1-3, the equilibrium quantity limit under hybrid policy is the same as the emission cap under quantity policy, and the equilibrium trigger price under hybrid policy is the same as the equilibrium emission tax under price policy. It means that hybrid policy is a mixture of price and quantity instruments. Thus, it is not surprising to have the equilibrium expected social cost of hybrid policy lying within those of price and quantity policies as displayed in (16)-(17). In other words, either price or quantity policy will have the lowest social cost among the three.

However, when general indexed quantity instrument is considered, th above outcomes may change. By comparing (9) and (12), we get

$$SC_I^* - SC_q^* = \frac{-\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2} \leq 0. \tag{18}$$

This suggests that general indexed quantity is always preferred to quantity instrument, a finding similar to Newell and Pizer's (2008). Combining (16) and (18), we have

$$SC_I^* \leq SC_q^* \leq SC_h^* \leq SC_p^* \tag{19}$$

when $d_2 \geq c_2$. That is, general indexed quantity instrument is preferred when the slope of marginal damage of emissions is greater than that of marginal abatement cost of emissions. Next, we discuss the case of $d_2 \leq c_2$. Equations (7) and (12) imply

$$\begin{aligned} SC_I^* - SC_p^* &= \frac{-\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2} - \frac{(d_2 - c_2)\sigma_\epsilon^2}{2c_2^2} \geq \ (\leq)\ 0 \\ &\text{iff} \quad \frac{\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2} \leq \ (\geq)\ \frac{(c_2 - d_2)\sigma_\epsilon^2}{2c_2^2}. \end{aligned} \tag{20}$$

And, by (11) and (12), we have

$$\begin{aligned} SC_I^* - SC_h^* &= \frac{-\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2} - \frac{(d_2 - c_2)E(\epsilon^2 \mid \epsilon > 0)}{2c_2^2} \geq \ (\leq)\ 0 \\ &\text{iff} \quad \frac{\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2} \leq \ (\geq)\ \frac{(c_2 - d_2)}{2c_2^2} E(\epsilon^2 \mid \epsilon > 0). \end{aligned} \tag{21}$$

Thus, relative cost efficiency of the four instruments would depend on covariance sizes of cost shock and index variable as well. If $\frac{\sigma_{x\epsilon}^2}{(c_2+d_2)\sigma_x^2} \leq \frac{(c_2-d_2)}{2c_2^2} E(\epsilon^2 \mid \epsilon > 0)$, we have

$$SC_p^* \leq SC_h^* \leq SC_I^* \leq SC_q^* \tag{22}$$

by (17)-(18) and (20)-(21). It suggests that price instrument is preferred. If $\frac{(c_2-d_2)}{2c_2^2}$ $E(\epsilon^2 \mid \epsilon > 0) < \frac{\sigma_{x\epsilon}^2}{(c_2+d_2)\sigma_x^2} \leq \frac{(c_2-d_2)\sigma_\epsilon^2}{2c_2^2}$, then (17)-(18) and (20)-(21) imply

$$SC_p^* \leq SC_I^* \leq SC_h^* \leq SC_q^*, \tag{23}$$

meaning that price instrument is still preferred. Finally, if $\frac{\sigma_{x\epsilon}^2}{(c_2+d_2)\sigma_x^2} > \frac{(c_2-d_2)\sigma_\epsilon^2}{2c_2^2}$, then we have

$$SC_I^* \leq SC_p^* \leq SC_h^* \leq SC_q^* \tag{24}$$

by (17)-(18) and (20)-(21). This implies that general indexed quantity instrument is preferred. These outcomes are summarized below.

Proposition 6. *Suppose that the regulator considers instruments of price, quantity, hybrid, and general indexed quantity in reducing pollutant emissions. Then, we have the following.*
(i) *If* $d_2 \geq c_2$, *general indexed quantity is preferred to the other three instruments.*
(ii) *If* $d_2 < c_2$ *and* $\frac{\sigma_{x\epsilon}^2}{(c_2+d_2)\sigma_x^2} \leq \frac{(c_2-d_2)\sigma_\epsilon^2}{2c_2^2}$, *price is preferred to the other three instruments.*
(iii) *If* $d_2 < c_2$ *and* $\frac{\sigma_{x\epsilon}^2}{(c_2+d_2)\sigma_x^2} > \frac{(c_2-d_2)\sigma_\epsilon^2}{2c_2^2}$, *general indexed quantity is preferred to the other three instruments.*

Proposition 6 states that general indexed quantity will be preferred when the slope of marginal damage of emissions exceeds that of marginal abatement cost of emissions, or when correlation between cost shock and index variable is high enough. These outcomes are the same as Newell and Pizer's (2008), who calculate social welfares of price, quantity, and general indexed quantity policies. Since the equilibrium expected social cost of hybrid policy is within those of price and quantity policies based on Proposition 5; comparing the costs of price, quantity, and general indexed quantity policies can help us find the instrument with the lowest cost, like Newell and Pizer (2008) do. Moreover, the reasons for general indexed quantity being the most cost-effective policy are the same in both Newell and Pizer's (2008) and this studies.

Nevertheless, the outcome may change when price policy is excluded, which is possible under political pressures. Results of equations (19)-(24) are summarized below.

Proposition 7. *Suppose that the regulator considers instruments of quantity, hybrid, and general indexed quantity in reducing pollutant emissions. Then, we have the fol-*

lowing.

(i) *If* $d_2 \geq c_2$, *general indexed quantity is preferred to the other two instruments.*

(ii) *If* $d_2 < c_2$ *and* $\frac{\sigma^2_{x\epsilon}}{(c_2+d_2)\sigma^2_x} \leq \frac{(c_2-d_2)E(\epsilon^2 \mid \epsilon>0)}{2c_2^2}$, *hybrid is preferred to the other two instruments.*

(iii) *If* $d_2 < c_2$ *and* $\frac{\sigma^2_{x\epsilon}}{(c_2+d_2)\sigma^2_x} > \frac{(c_2-d_2)E(\epsilon^2 \mid \epsilon>0)}{2c_2^2}$, *general indexed quantity is preferred to the other two instruments.*

5. Conclusions

This paper explores the cost effectiveness of four emission-reducing policies: price, quantity, hybrid, and general indexed quantity. For each policy instrument, we construct a two-stage to characterize interactions between the regulator and a firm. All SPEs are derived and compared. We have several major findings. First, the equilibrium quantity limit under hybrid policy equals the equilibrium emission cap under quantity policy, and the equilibrium trigger price under hybrid policy equals the equilibrium emission tax under price policy. Accordingly, the equilibrium expected social cost under hybrid policy is within those under price and quantity policies. Second, general indexed quantity is preferred to the other three instruments when the slope of marginal damage of emissions exceeds that of marginal abatement cost of emissions, or when correlation of cost shock and index variable is high enough. For the rest cases, price instrument is preferred. Third, if price control is not politically feasible, then general indexed quantity instrument is preferred to the other two instruments when the previous slope or correlation conditions holds. And hybrid policy is preferred for the other situations.

Current literature focuses on welfare or cost analyses of pollutants-reducing policy instruments. When global warming problems become more and more serious, environmental effectiveness of these policy instruments would become more significant too.

Thus, we will investigate this issue in our next research project.

Appendix

Proof of Proposition 1: It is easy to see that e_t^* must satisfy the condition of $C'(e_t^*,\ \epsilon)+t=0$. Thus, $e_t^* = \frac{c_1+\epsilon-t}{c_2}$. The second-order condition holds because $C''(e,\ \epsilon) > 0$. Given e_t^*, the regulator will choose t^* to solve the problem of

$$\min_t \ SC_p \equiv D(e_t^*) + EC(e_t^*,\ \epsilon),$$

where

$$\begin{aligned} & D(e_t^*) + EC(e_t^*,\ \epsilon) \\ = & \int_{-\underline{\epsilon}}^{\underline{\epsilon}} \left[d_0 + d_1 e_t^* + \frac{d_2}{2}(e_t^*)^2 \right] f(\epsilon)d\epsilon + \int_{-\underline{\epsilon}}^{\underline{\epsilon}} \left[c_0 - c_1 e_t^* + \frac{c_2}{2}(e_t^*)^2 - \epsilon e_t^* \right] f(\epsilon)d\epsilon \\ = & (c_0+d_0) + \frac{(d_1-c_1)}{c_2}(c_1-t) + \frac{(c_2+d_2)}{2c_2^2}(c_1-t)^2 + \frac{(d_2-c_2)\sigma_\epsilon^2}{2c_2^2} \end{aligned}$$

because

$$\begin{aligned} \int_{-\underline{\epsilon}}^{\underline{\epsilon}} e_t^* f(\epsilon)d\epsilon &= \frac{c_1-t}{c_2}, \\ \int_{-\underline{\epsilon}}^{\underline{\epsilon}} (e_t^*)^2 f(\epsilon)d\epsilon &= \frac{(c_1-t)^2}{c_2^2} + \frac{\sigma_\epsilon^2}{c_2^2}, \text{ and} \\ \int_{-\underline{\epsilon}}^{\underline{\epsilon}} \epsilon e_t^* f(\epsilon)d\epsilon &= \frac{\sigma_\epsilon^2}{c_2}. \end{aligned}$$

Then, the first-order condition for t^* is $\frac{\partial SC_p}{\partial t} = \frac{(c_1-d_1)}{c_2} - \frac{(c_2+d_2)}{c_2^2}(c_1-t) = 0$. Thus, $t^* = \frac{c_1 d_2 + c_2 d_1}{c_2+d_2}$. Its second-order condition holds because $\frac{\partial^2 SC_p}{\partial t^2} = \frac{(c_2+d_2)}{c_2^2} > 0$. At t^*, we have $(c_1 - t^*) = \frac{c_2(c_1-d_1)}{c_2+d_2}$, and the equilibrium expected social cost is

$$SC_p^* = c_0 + d_0 + (d_1-c_1)\bar{e}^* + \frac{(c_2+d_2)}{2}(\bar{e}^*)^2 + \frac{(d_2-c_2)}{2c_2^2}\sigma_\epsilon^2,$$

where $\bar{e}^* = \frac{c_1-d_1}{c_2+d_2} > 0$. $\square$

Proof of Proposition 2: Since deriving e_q^* is the same as that in (25)-(27), we have $e_q^* = \bar{e}_q$. Next, given $e_q^* = \bar{e}_q$, the regulator will choose $\bar{e}_q^*$ to solve the problem of

$$\min_{\bar{e}_q} SC_q \equiv D(\bar{e}_q) + EC(\bar{e}_q, \epsilon),$$

where $D(\bar{e}_q) + EC(\bar{e}_q, \epsilon) = c_0 + d_0 + (d_1 - c_1)\bar{e}_q + \frac{(c_2+d_2)}{2}\bar{e}_q^2$. From the first-order condition $\frac{\partial SC_q}{\partial \bar{e}_q} = d_1 - c_1 + (c_2 + d_2)\bar{e}_q$, we obtain the optimal emission cap $\bar{e}_q^* = \frac{c_1 - d_1}{c_2 + d_2}$. The second-order condition holds due to $\frac{\partial^2 SC_q}{\partial \bar{e}_q^2} = (c_2 + d_2) > 0$. At $(\bar{e}_q^*, e_q^*)$, the regulator's equilibrium expected social cost is

$$SC_q^* = c_0 + d_0 + (d_1 - c_1)\bar{e}_q^* + \frac{(c_2 + d_2)}{2}(\bar{e}_q^*)^2.$$

□

Proof of Proposition 3: The associated SPEs are derived by the following two steps.

Step 1: We first calculate the firm's optimal emission e_h^*. Since it has two possible ranges, $(0, \bar{e}]$ and $(\bar{e}, \infty)$, we need to consider both intervals, then compare the corresponding equilibrium total costs. The emission level with a smaller equilibrium total cost is e_h^*. Firm's optimal emission e_1^* in interval $(0, \bar{e}]$ solves the following problem.

$$\min_{e} C(e, \epsilon) \text{ s.t. } e \leq \bar{e}. \tag{25}$$

Its Lagrange function is $L = C(e, \epsilon) - \lambda[\bar{e} - e]$, where λ is the Lagrange multiplier. The first-order conditions are

$$\frac{\partial L}{\partial e} = C'(e, \epsilon) + \lambda \geq 0, \; e\frac{\partial L}{\partial e} = 0, \tag{26}$$

$$\frac{\partial L}{\partial \lambda} = e - \bar{e} \leq 0, \; \lambda \geq 0, \; \lambda\frac{\partial L}{\partial \lambda} = 0. \tag{27}$$

If $e_1^* < \bar{e}$, then $\lambda = 0$ by (27), hence $C'(e, \epsilon) \geq 0$ by (26). This contradicts the assumption of $C'(e, \epsilon) < 0$. Thus, we must have $e_1^* = \bar{e}$ and $\lambda^* = -C'(\bar{e}, \epsilon) > 0$. In this case, the firm's optimal total cost is $FC_1 \equiv C(\bar{e}, \epsilon)$.

Next, firm's optimal emission e_2^* in interval $(\bar{e}, \infty)$ solves the problem of

$$\min_{e} C(e, \epsilon) + p_s[e - \bar{e}] \quad \text{s.t.} \quad e > \bar{e}. \tag{28}$$

Its Lagrange function is $\bar{L} = C(e,\ \epsilon) + p_s[e - \bar{e}] - \bar{\lambda}[e - \bar{e}]$, where $\bar{\lambda}$ is the Lagrange multiplier. The first-order conditions are

$$\frac{\partial \bar{L}}{\partial e} = C'(e,\ \epsilon) + p_s - \bar{\lambda} \geq 0,\ e\frac{\partial \bar{L}}{\partial e} = 0, \quad (29)$$

$$\frac{\partial \bar{L}}{\partial \bar{\lambda}} = \bar{e} - e \leq 0,\ \bar{\lambda} \geq 0,\ \bar{\lambda}\frac{\partial \bar{L}}{\partial \bar{\lambda}} = 0. \quad (30)$$

Since $e_2^* > \bar{e}$, we must have $\bar{\lambda} = 0$ and $p_s = -C'(e_2^*,\ \epsilon)$. Under the circumstance, the firm's optimal total cost is $FC_2 \equiv C(e_2^*,\ \epsilon) + p_s[e_2^* - \bar{e}]$. To guarantee $e_2^* > \bar{e}$, we need $p_s < -C'(\bar{e},\ \epsilon)$.

By comparing FC_1 and FC_2, we obtain e_h^* as follows.

$$e_h^* = \begin{cases} e_1^* = \bar{e} & \text{if } FC_1 \leq FC_2, \\ e_2^* \text{ with } p_s = -C'(e_2^*,\ \epsilon) & \text{if } FC_2 \leq FC_1 \text{ and } p_s < -C'(\bar{e},\ \epsilon). \end{cases} \quad (31)$$

Step 2: Given e_h^* in (31), we can derive regulator's optimal hybrid policy $(\bar{e}_h^*,\ p_s^*)$. If $e_h^* = e_1^*$, the regulator will choose $\bar{e}_h^*$ to solve the problem of

$$\min_{\bar{e}} D(\bar{e}) + EC(\bar{e}, \epsilon),$$

where $D(\bar{e}) + EC(\bar{e}, \epsilon) = c_0 + d_0 + (d_1 - c_1)\bar{e} + \frac{(c_2+d_2)}{2}\bar{e}^2$. It is easy to get $\bar{e}_h^* = \frac{c_1-d_1}{c_2+d_2} > 0$, and the second order condition holds because $(c_2 + d_2) > 0$. By contrast, if $e_h^* = e_2^*$, we have $e_h^* = \frac{c_1+\epsilon-p_s}{c_2}$ due to $p_s = -C'(e_2^*,\ \epsilon)$. Accordingly, we have $E(e_h^*) = \frac{c_1-p_s}{c_2}$, $E(e_h^*)^2 = \frac{(c_1-p_s)^2}{c_2^2} + \frac{\sigma_\epsilon^2}{c_2^2}$, and $E(\epsilon e_h^*) = \frac{\sigma_\epsilon^2}{c_2}$. The regulator will choose p_s^* to solve the problem of

$$\min_{p_s}\ D(e_h^*) + EC(e_h^*, \epsilon), \quad (32)$$

where $D(e_h^*) + EC(e_h^*, \epsilon) = c_0 + d_0 + (d_1 - c_1)\frac{(c_1-p_s)}{c_2} + \frac{(c_2+d_2)}{2}[\frac{(c_1-p_s)^2}{c_2^2} + \frac{\sigma_\epsilon^2}{c_2^2}] - \frac{\sigma_\epsilon^2}{c_2}$. By solving (32), we get $p_s^* = \frac{c_1 d_2 + c_2 d_1}{c_2+d_2} > 0$, and the second-order condition holds due to $\frac{c_2+d_2}{c_2^2} > 0$. At p_s^*, we have $E(e_h^*) = \frac{c_1-d_1}{c_2+d_2} = \bar{e}^*$ and $p_s^* = -EC'(e_h^*,\ \epsilon)$.

It remains to check the consistency between (31) and $(\bar{e}_h^*,\ p_s^*)$. At p_s^*, we have

$$e_h^* = e_2^* = \frac{c_1 + \epsilon - p_s^*}{c_2} = \frac{c_1 + \epsilon}{c_2} - \frac{1}{c_2}[\frac{c_1 d_2 + c_2 d_1}{c_2 + d_2}] = \bar{e}^* + \frac{\epsilon}{c_2}.$$

Thus, $e_h^* \geq \ (\leq)\ \bar{e}^*$ iff $\epsilon \geq \ (\leq)\ 0$. If $\epsilon < 0$, we have $e_h^* < \bar{e}^*$. This contradicts the hypothesis of $e_2^* > \bar{e}^*$. Thus, the firm's optimal emission is $e_1^* = \bar{e}^*$ for $\epsilon < 0$. With respect to $\epsilon > 0$, we have

$$\begin{aligned} FC_1 - FC_2 &= C(\bar{e}_h^*,\ \epsilon) - C(e_h^*,\ \epsilon) - p_s^*[e_h^* - \bar{e}_h^*] \\ &= \frac{c_1\epsilon}{c_2} + \frac{\epsilon^2}{c_2} - \frac{c_2}{2}[(e_h^*)^2 - (\bar{e}_h^*)^2] - \frac{\epsilon p_s^*}{c_2} \\ &= \epsilon \cdot [\frac{p_s^*}{c_2} + \frac{\epsilon}{2c_2} - \frac{p_s^*}{c_2}] \\ &= \frac{\epsilon^2}{2c_2} > 0. \end{aligned}$$

It means that $FC_1 \geq FC_2$, hence the firm will choose e_2^* for $\epsilon > 0$. Moreover, for $\epsilon > 0$,

$$p_s^* + C'(\bar{e}_h^*,\ \epsilon) \ = \ \frac{(c_1d_2 + c_2d_1)}{c_2 + d_2} - c_1 + c_2 \cdot \frac{(c_1 - d_1)}{c_2 + d_2} - \epsilon = -\epsilon < 0.$$

This suggests that $p_s^* < -C'(\bar{e}_h^*,\ \epsilon)$ holds for $\epsilon > 0$. In sum, if $\epsilon < 0$, e_2^* does not exist, then the firm's optimal emission is $e_1^* = \bar{e}_h^*$. In contrast, if $\epsilon > 0$, we have $e_h^* = e_2^*$.

Finally, at hybrid equilibrium ($\bar{e}_h^* = \frac{c_1-d_1}{c_2+d_2},\ p_s^* = \frac{c_1d_2+c_2d_1}{c_2+d_2}$), the regulator's expected social cost is

$$\begin{aligned} SC_h^* &= \int_{-\underline{\epsilon}}^{0} [D(\bar{e}^*) + C(\bar{e}^*,\ \epsilon)]\, f(\epsilon)d\epsilon + \int_{0}^{\underline{\epsilon}} [D(e_2^*) + C(e_2^*,\ \epsilon)]\, f(\epsilon)d\epsilon \\ &= c_0 + d_0 + (d_1 - c_1)\bar{e}^* + \frac{c_2 + d_2}{2}(\bar{e}^*)^2 - \bar{e} \cdot [E(\epsilon \mid \epsilon < 0) + E(\epsilon \mid \epsilon > 0)] \\ &\quad + E(\epsilon \mid \epsilon > 0) \cdot [\frac{(d_1 - c_1)}{c_2} + \frac{\bar{e}^*(c_2 + d_2)}{c_2}] + E(\epsilon^2 \mid \epsilon > 0) \cdot [\frac{(c_2 + d_2)}{2c_2^2} - \frac{1}{c_2}] \\ &= c_0 + d_0 + (d_1 - c_1)\bar{e}^* + \frac{(c_2 + d_2)}{2}(\bar{e}^*)^2 + \frac{(d_2 - c_2)}{2c_2^2}E(\epsilon^2 \mid \epsilon > 0), \end{aligned}$$

where $E(\epsilon \mid \epsilon > 0) = \int_0^{\underline{\epsilon}} \epsilon f(\epsilon)d\epsilon$ and $E(\epsilon^2 \mid \epsilon > 0) = \int_0^{\underline{\epsilon}} \epsilon^2 f(\epsilon)d\epsilon$. □

Proof of Proposition 4: As in Proposition 2, given emission limit $\bar{e}(x) = a + rx$, the firm's optimal emission level is $e_I^* = a + rx$. And given $e_I^* = \bar{e}(x)$, the regulator will choose $(a^*,\ r^*)$ to minimize the expected social cost

$$\begin{aligned} & SC_I \equiv D(\bar{e}(x)) + EC(\bar{e}(x),\ \epsilon) \\ =\ & (c_0 + d_0) + (d_1 - c_1)[a + r\bar{x}] + \frac{(c_2 + d_2)}{2}[a^2 + 2ar\bar{x} + r^2(\sigma_x^2 + \bar{x}^2)] - r\sigma_{x\epsilon}. \quad (33) \end{aligned}$$

The first-order conditions are

$$\frac{\partial SC_I}{\partial a} = d_1 - c_1 + (c_2 + d_2)[a + r\bar{x}] = 0, \text{ and} \tag{34}$$

$$\frac{\partial SC_I}{\partial r} = \bar{x}(d_1 - c_1) + (c_2 + d_2)[a\bar{x} + r(\sigma_x^2 + \bar{x}^2)] - \sigma_{x\epsilon} = 0. \tag{35}$$

By solving (34)-(35), we get $a^* = \frac{(c_1-d_1)\sigma_x^2 - \bar{x}\sigma_{x\epsilon}}{(c_2+d_2)\sigma_x^2}$ and $r^* = \frac{\sigma_{x\epsilon}}{(c_2+d_2)\sigma_x^2}$ with $a^* + r^*\bar{x} = \bar{e}^*$. Substituting $a^* + r^*\bar{x} = \bar{e}^*$ into (33) yields regulator's equilibrium expected social cost

$$SC_I^* = (c_0 + d_0) + (d_1 - c_1)\bar{e}^* + \frac{(c_2 + d_2)}{2}(\bar{e}^*)^2 - \frac{\sigma_{x\epsilon}^2}{(c_2 + d_2)\sigma_x^2}.$$

□

References

Cline, W. R. (2004): "Meeting the challenge of global warming," Institute for International Economics.

Jacoby, H. D., and Ellerman, A. D. (2004): "The safety valve and climate policy," *Energy Policy* 32, 481-491.

Newell, R. G., and Pizer, W.A. (2003): "Regulating stock externalities under oncertainty," *Journal of Environmental Economics and Management*, 45, 416-432.

Newell, R. G., and Pizer, W. A. (2008) "Indexed regulation," *Journal of Environmental Economics and Management*, 56 221-233.

Pizer, W. A. (2002): "Combining price and quantity controls to mitigate global climate change," *Journal of Public Economics*, 85, 409-434.

Roberts, M. J., and Spence, M. (1976): "Effluent charges and licenses under uncertainty," *Journal of Public Economics*, 5, 193-208.

Webster, M., Wing, I. S., and Jakobovits, L. (2010): "Second-best instruments for near-term climate policy: Intensity targets vs. the safety valve," *Journal of Environmental Economics and Management*, 59, 250-259.

Weitzman, M. L. (1974): "Prices vs. quantities," *Review of Economics Studies*, 41, 477-491.

Weitzman, M. L. (1978): "Optimal rewards for economic regulation," *American Economic Review*, 68, 683-691.

Using Regional Economic Impact Analysis to Decide Public Promotion of Seismic Retrofit in the Northern Taiwan

Y.L. Kuo[1] D. Shaw[2] H.C. Lin[3] M.C. Chang[4] T.M. Kao[5]

Abstract

The direct damages caused by earthquake, such as impaired buildings, may interfere with normal business operation, and disrupt the function of industrial chain. Such economic impacts can be evaluated by the input-output analysis developed by Leontief. In this paper, two scenario earthquakes in the northern Taiwan with a return period of 475 years – Hsinchu Hsincheng earthquake (magnitude 7.5 M_L and 10 km in depth) and the Yilan Nan'ao earthquake (magnitude 7.9 M_L and 7 km in depth) are simulated by Taiwan Earthquake Loss Estimation System (TELES) developed by the National Center for Research on Earthquake Engineering (NCREE). Moreover, the regional input-output production table (IO) estimated by Lin and Kao (2008) is considered as the tool in the regional economic impact analysis. The results show that all kinds of losses cause by Hsincheng earthquake are all greater than those of Nan-ao earthquake, which is should be a main scenario considered during the disaster reduction plan in the future. The reason why the Hsincheng caused a comparatively large loss mainly lies in that the intensive seismic area of the Hsincheng earthquake is located in Hsinchu. The local building is mainly for manufacturing, of which the output value and the repercussion effect are both higher than those of the buildings in the intensive seismic area of Nan-ao earthquake. Among the five industries which have comparatively great earthquake loss in the northern Taiwan, the construction industry has a great loss, but the demand of reconstruction will also spur the corresponding output value. Therefore, the industries affected the most are the manufacturing, food services and entertainment, storage and retail trade, public and construction industries. Compared with the top five affected industries in two scenario earthquake, the Nan-ao earthquake causes relatively more loss in the storage and retail trade, and food services and entertainment. Most of those industries' repercussion effects are in the central and southern Taiwan.

The loss in the manufacturing caused by the earthquake in the northern Taiwan is huge, and its repercussion effect is also large. Therefore, the government shall give first rank to encourage the manufacturing to carry out the disaster reduction, such as seismic retrofit, or to provide seismic evaluation to manufacturing, which can make them conduct the disaster reduction voluntarily. The losses of the storage and retail

[1] Senior Assistant Research Fellow, National Science and Technology Center for Disaster Reduction
[2] President of Chung-Hua Institution for Economic Research
[3] Associate Professor, Department of Applied Economics, National Chiayi University
[4] Graduate Student, Institute of Natural Resources Management, National Taipei University
[5] Assistant Professor, Finance Department, Ming Chuan University

trade, and food services and entertainment are also huge. Seismic retrofit should be encouraged in these industries. The other measure to reduce the loss in agriculture is that the government can purchase agricultural products in the central and southern Taiwan after disaster and offer survivors in the northern Taiwan, which can relieve the earthquake disaster and stop repercussion effect to agriculture. Due to the restrictions that the input-output analysis adopted in the research has constant returns to scale, no substitution for inputs, etc., the adaptive behavior during disasters cannot be included. Therefore, the simulated economic impact in this paper is the most serious situation of disasters.

Keywords: economic impact analysis, regional input-output model, TELES, seismic retrofit

1. Introduction

Taiwan is located on the ring of fire - Circum-Pacific seismic belt - and face frequent earthquakes. Compared with other disasters, such as typhoon and flood, the uncertainty of earthquake is quite high. Therefore, it is hard to forecast that when and where the earthquake will hit and the scale of it. The past experience has proven that the earthquake, which has a considerably wide influence, will bring about disastrous casualties and property loss. An earthquake measuring 9.3 on the Richter scale occurred in Taiwan on the dawn of September 21, 1999. According to the data from Central Weather Bureau, Taiwan, the epicenter of the earthquake is 9 km to the west of the Sun Moon Lake in Nantou County, with a depth of 8 km. The earthquake caused casualties of 2413 people, and over 11,000 people were injured and almost 110,000 houses completely or partially collapsed. Besides the disastrous casualties and property loss, the ultra high voltage electric tower at Chungliao Township, Nantou County collapsed, which caused a power failure across Taiwan. Although there was no collapse of and damage to the factory building, the production line of the wafer plant, with an annual output value of more than $10 billion NTD, was completely stopped due to the power breakdown. The semi-finished products of wafer in the production line were discarded, which brought serious losses to the manufacturer. At the same time, the US stock market, upon learning the earthquake in Taiwan, dropped sharply. The spot price of DRAM rose immediately, which influenced the global semiconductor industry. Since nearly all of the wafers in the world are produced in Taiwan by OEMs, the earthquake not only brings loss to Taiwan, but also interrupts the supply chain of the global electronics industry. Beside the production loss, firms confront the loss of losing orders.

In order to design a disaster reduction plan which requires the distribution of loss caused by earthquake, the project “Strengthening the Disaster Prevention and Protection Abilities of Taipei County/City” sets two scenario earthquakes with 475 years return periods to simulate the maximum damage to the Taipei metropolitan area. This paper adopted these two scenario earthquakes and analyzed the direct loss and the production or output loss generated by the industrial chain.

2. Literature Review

Earthquakes cause various damages to society. According to the earthquake intensity scale defined by Central Weather Bureau, Taiwan, the earthquake causes nearly no damages to the ground below 7. The earthquake mainly causes damages to facilities, buildings, etc directly. Therefore, the main and direct impact is to the buildings, as well as people and objects inside; such damages are called direct impact or direct loss. Okuyama (2007) suggested that the loss caused by the discontinuity of economic activities, production and consumption behaviors and commercial activities which is from direct loss is indirect loss. That is to say, the economic unit stops the production because of the discontinuity of some inputs, due to causes beyond their controls, thus leading to production or business loss; these are indirect loss. The direct loss and indirect loss are together known as economic impacts. According to past studies on the economic impact of disasters, the indirect loss of disaster and the evaluation methods are generalized respectively as follows:

2.1 Definition of Indirect Loss of Disaster

The indirect loss of disaster means the production is stopped because of the discontinuity of inputs. The inputs can be further divided into its owned capital including buildings, equipments and labors, the upstream raw materials, and the infrastructure, such as water, electricity, transportation, etc.

a. Influence of capital damage on production and consumption

The production or consumption will be disrupted when the earthquake damages capitals mainly including buildings and equipments in that.

b. Influence of supply of raw materials on industrial chain

Rose (2004) suggested that when work is stopped, the factory cannot deliver the goods to its clients; to the clients, they lack the raw materials provided from the upstream, and cannot continue the production and deliver goods to their clients. Finally, the whole industrial chain will be affected. Cochrane (2004) indicated that the influence of the occurrence of disaster to the industry is a ripple effect, which means that the detainment of a certain flow path of supply chain will affect the entire supply chain. Werling and Horst (2009) pointed out that indirect loss means the industrial chain is affected. The upstream industry cannot provide the raw materials, and the downstream consumers cannot get the due service.

c. Influence caused by the discontinuity of infrastructures, such as water, electricity, and transportation

Parker et al. (1987) mentions that the damage caused by the flood to the public construction leads to the decrease of export and the increase of import. The factory cannot be in normal operation, and the daily life of people is not convenient because the electricity and water cannot be supplied. When infrastructure is damaged and hard to recover, the work has to be recovered by the external resources. Therefore, the import demand increases. However, when all of the local resources are firstly used in the local reconstruction, the export decreases. UNECLAC (2003) suggested that the influence caused by the insufficient energy supply, such as power failure, interruption in petroleum or fuel gas supply, would have a great impact on the industries. The manufacturer cannot send the goods to the consumers on time. If the products are agricultural products, which cannot be stored for a long time, or parts that need to be transshipped or processed, the customers may transfer the order and import from the other manufacturers or abroad. As a result, even if not directly damaged because of the insufficient power source such as water, electricity, and fuel gas, as well as the interruption of communication, the manufacturers will still suffer the loss because they cannot deliver the goods or cannot acquire the raw material for production.

2.2 Literature review on economic impact analysis of earthquake

Many studies have been conducted on evaluation of the loss and economic impact cause by earthquakes. The literatures that focus on the economic impact of seismic hazards, meaning those that estimate the influence of industrial chain and/or the interruption of the lifeline, and public facilities and services, are reviewed below. These studies often adopt the input-output analysis, or macroeconomic models, such as computable general equilibrium (CGE), as the main analytical method. The common topics include the various impacts caused by the disaster, including the direct capital damage, product loss and production loss, as well as the economic impacts triggered by the discontinuity of the electricity, communications and transportation, which are introduced respectively as follows:

The first paper that systematically analyzes the economic impact of earthquake and is Ellson, Milliman, & Roberts (1984), who reviewed past literatures on the economic impact of disasters, and found several problems: (a) the method is difficult to be generalized, and is often studied after the disaster; (b) the base period is not properly adopted, which should be “with and without”, rather than “before and after the disaster”, (c) the flow and stock loss are usually not clearly distinguished. They also pointed out that the earthquake causes damages in different areas at the same time. The effect interacts among the areas. Moreover, the natural disaster belongs to impact to the supply side. With the standard statistical area in metropolis of Charleston as the range, they analyzed three cities: Charleston, Barkeley and Dorchester. The macroeconomic model of the area was established by various statistics to estimate the household stock loss, capital stock damage, traffic flow, population, the difference between the non-agricultural income and the personal income, and the present values were converted into the analysis of regional economies. The study defined all the influences, such as residence and capital stock, hazard mitigation measures, communications and transport, related to the disaster as the influence of supply side, in order to analyze the influence of supply side caused by earthquake. Yamano, Yoshio, & Yoshiharu (2007) analyzed the economic loss of the Great Hanshin Awaji Earthquake by geographic information system (GIS) and the regional input-output model. They found that the regional distribution of industrial loss and direct economic loss are different, of which the reason is related to the industrial structure, population distribution and the accessibility of transport. Wu (2003) constructed the regional input-output model of central Taiwan, in order to evaluate the economic impact on the area caused by the input of reconstruction fund for the tourism after the 921 Earthquake. The results showed that the reconstruction fund benefits the recovery of all industries in the area. However, the output increase of each sector depends on its linkage with others.

Among studies on the economic impact caused by the interruption of electricity and transport, Rose, et al. (1997) explored the economic impact of the power failure caused by the earthquake in Memphis, Tennessee by input-output table and the linear programming model. Besides the immediate loss, the power failure has follow-up impacts both on the commodity manufacture and service, with associated impacts on the suppliers and customers. Rose and Guha (2004) estimated the impacts of power failure caused by earthquake on the Shelby county by CGE. Boarnet (1998) estimated the loss of Northridge earthquake in 1994 by the survey on manufacturers. Results showed that 43% of the manufacturers in the Los Angeles suffered various impacts on the impaired traffic system, and these manufacturers indicated that 39% of the production loss on average was from the impaired traffic system. Cho, et al. (2001) estimated damages to the transportation and productivity, and the impacts of economy from a 7.1 magnitude earthquake in Los Angeles. He analyzed the impacts by integrating the allocation models, the input-output table and the transportation network. Okuyama (2004) analyzed the direct impact on the buildings (residence), factories, transport facilities (port, railway and public road), lifelines (water, electricity and gas) caused by the Great Hanshin Awaji Earthquake in 1995. Those impacts declined the income and total output in that area, and also spread to the other area of Japan. Rose (2004) considered the input-output (IO) as the analysis tool for economic impact of disaster. Based on the above, most studies used this method or combined it with other methods for the estimation.

3. Theoretical model of Input-output Analysis

Input-output analysis is developed from Walras`s general equilibrium model and simplified by Leontief's in the 1930s. Input-output analysis probes into the relationship between production and consumption of all industrial departments, and is used to show the inputs or labors of each department needed to produce one unit production during a period, or the distribution of the production to each intermediate input department and eventually consumption department. If a matrix is used to show the statistics between the productions of all industrial departments, these statistics form the industrial linkage table, which is also called input-output table. This model has following three basic hypotheses: (a.) hypothesis of single product, (b.) hypothesis of fixed coefficient, (c.) hypothesis of fixed proportion. The above hypotheses also show this production function is Leontief's production function, and three characteristics. (a.) Constant returns to scale in the production. (b.) The production is produced by inputs at a fixed proportion. (3) No substitutions among inputs (Wang, 1986). The analytical methods are respectively explained as follows: the framework of input-output analysis, the demand-side and supply-side input-output model, the multi-regional input-output model, and the index of sensitivity and dispersion.

3.1 The framework

Input-output analysis is based on the transaction table (see Table 1).

Table 1. Framework of the transaction table

			Intermediate demand Purchasing department of industry 1 2 …….j……. n	Final demand	Aggregate demand = aggregate output
Inter-med-iat input	Sales dep.	1 2 ⋮ i ⋮ n	Z_{11} Z_{12} …Z_{1j} … Z_{1n} Z_{21} Z_{22} Z_{2n} ⋮ ⋮ ⋮ Z_{ij} ⋮ ⋮ ⋮ Z_{n1} Z_{n2} … Z_{nj} … Z_{nn}	Y_1 Y_2 ⋮ Y_i ⋮ Y_n	X_1 X_2 ⋮ X_i ⋮ X_n
Ori-ginal input	Value added		W_1 W_2 ……W_j…W_n		
	Total input = total production		X_1 X_2 ……X_j…… X_n		

Source: Miller and Blair(1985)

Intermediate demand refers to the demand for the products of other industrial departments as raw material during the production of certain product or service by an industrial department. Zij indicates that when the j department produce, i product is needed as input. Zij is the demand of j department for products of i department. Final demand refers to products which are to be ultimately consumed by economic entities but not used as intermediate products for the production, and can be classified as domestic consumption (C), private investment (I), government expenditure (G), and net export (exports minus imports X-M) according to the functions. The original input is also called the basic input refers the inputs that are not produced by other industrial departments. The payment of production, such as the land, the labor, the capital, entrepreneurial spirit and governmental service etc, are included in the original input. According to the characters, the payment can be classified as rent (the land), reward for the labor service (the labor), interest (the capital), profit (entrepreneurial spirit) and indirect tax (governmental service). Thus, the original input also is called the value added. Here Wj indicates the original input of j department.

According to Miller and Blair (1985), input-output analysis can be divided into two classes: the demand side and the supply side. The discussion of these two models is as follows.

3.2 Demand Side Model

Xi indicates the content in the horizontal row of transaction table (Table 1), i.e. the purchasing department of industry composed of n industries and the final demand department. The summation of the intermediate demand and final demand is the aggregate demand. This is the demand-side model, and can be demonstrated through the following equations.

Aggregate output = intermediate demand + final demand

$$X_1 = Z_{11} + Z_{12} + \ldots + Z_{1n} + Y_1$$
$$\vdots$$
$$X_n = Z_{n1} + Z_{n2} + \ldots + Z_{nn} + Y_n \tag{1}$$

The above n equations can be expressed by matrixes.

$$\begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} Z_{11} + Z_{12} + \ldots + Z_{1n} \\ \vdots \\ Z_{n1} + Z_{n2} + \ldots + Z_{nn} \end{bmatrix} + \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix} \tag{2}$$

There is a proportion relationship between the aggregate output and intermediate demand. The unit number of products input of each department needed for the production of one unit product with the current production technology is expressed as $a_{ij} = Z_{ij} / X_j$. This relationship is called input coefficient. Equation 1 can be rewritten as:

$$\begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} a_{11}X_{11} + a_{12}X_{12} + \cdots + a_{1n}X_{1n} \\ \vdots \\ a_{n1}X_{n1} + a_{n2}X_{n2} + \cdots + a_{nn}X_{nn} \end{bmatrix} + \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix} \tag{3}$$

The right member X of Equation 3 is edited.

$$\begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n1} & \ldots & a_{nn} \end{bmatrix} \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} + \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix} \tag{4}$$

Equation 4 is expressed by vectors as Equation 5.

$$X = A_{n*n} * X + Y \tag{5}$$

Equation 5 is transposed and arranged as follows:

$$(I - A)X = Y \tag{6}$$

$$X = (I - A)^{-1} Y \tag{7}$$

X is the department output vector of n*1, Y the final demand vector of n*1, I the unit matrix, A the input coefficient matrix of n*n, and $(I\text{-}A)^{-1}$ the inverse matrix of Leontief, which means a department needs to purchase from each departments when the department needs to produce one more unit of product. Besides the direct effects, the indirect effects induced shall also be included. To demonstrate the effect on ***X*** -- the output of each department caused by the change of final demand ***Y***, Equation 7 shall be rewritten as Equation 8.

$$\Delta X = (I - A)^{-1} \Delta Y \qquad (8)$$

3.3 Supply Side Model

Xj indicates the vertical column of the transaction table, i.e. the sales department composed of n industries and the original input. The summation of the original input and the intermediate input of the products provided by all industries as raw materials during the production of j industry is denoted by Xj. This is the supply-side model, and can be demonstrated by the following equilibrium equations.

Aggregate input = intermediate input + basic input

$$X_1 = Z_{11} + Z_{21} + ... + Z_{n1} + W_1 \quad X_2 = Z_{12} + Z_{22} + ... + Z_{n2} + W_2 \quad \cdots \quad X_n = Z_{1n} + Z_{2n} + ... + Z_{nn} + W_n$$

(9)

The n equations above can be expressed by matrix:

$$[X_1 ... X_n] = [Z_{11} + Z_{21} + ... + Z_{n1} \quad Z_{12} + Z_{22} + ... + Z_{n2} \quad \cdots \quad Z_{1n} + Z_{2n} + ... + Z_{nn}] + [W_1 ... W_n]$$

(10)

There is a proportion relationship between the aggregate output and intermediate demand. When the input coefficient is expressed as $a_{ij} = Z_{ij} / X_i$, Equation 10 can be rewritten as:

$$[X_1 ... X_n] = [a_{11} X_{11} + a_{21} X_{21} + \cdots + a_{n1} X_{n1} \quad a_{12} X_{12} + a_{22} X_{22} + \cdots + a_{n2} X_{n2} \quad \cdots \quad a_{1n} X_{1n} + a_{2n} X_{2n} + \cdots + a_{nn} X_{nn}] + [W_1 ... W_n]$$

(11)

The right member X is taken out, and Equation 11 is arranged as Equation 12.

$$[X_1 ... X_n] = [X_1 ... X_n] \begin{bmatrix} \vec{a}_{11} & \vec{a}_{12} & ... & \vec{a}_{1n} \\ \vec{a}_{21} & \vec{a}_{22} & ... & \vec{a}_{2n} \\ \vdots & \vdots & & \vdots \\ \vec{a}_{n1} & \vec{a}_{n1} & ... & \vec{a}_{nn} \end{bmatrix} + [W_1 ... W_n] \qquad (12)$$

Equation 12 is expressed as Equation 13 by vectors.

$$X' = X' * \vec{A}_{n*n} + W \qquad (13)$$

$\vec{A}_{n*n}$ is the matrix of supply-side input coefficient. Equation 13 is transposed and arranged as following:

$$X'(I - \vec{A}) = W \qquad (14)$$

$$X' = W(I - \vec{A})^{-1} \qquad (15)$$

X' is the department output vector of 1*n, ***W*** the basic input vector of 1*n, I the unit matrix, A the input coefficient matrix of n*n, and $(I\text{-}A)^{-1}$ the inverse matrix of Leontief. To demonstrate the effect on ***X'***-- the output of each department caused by the change of basic input ***W***, Equation 15 shall be rewritten in the form of Equation 16.

$$\Delta X = \Delta W(I - A)^{-1} \quad (16)$$

3.4 The Multi-regional Input-output Model

Though the national economic analysis can be provided by the national input-output table, the development of regional industries in the country cannot be analyzed. The regional input-output structure of each industry, the distribution of products, the flow of products and the mutual effects between different industries shall be understood. The analysis shall be made when changes of the final demand of a certain region affect the development of other regional industry in the region (Wang, 1994).

The introduction of setting up multi-regional input-output model made by Linetal is hereby referenced. Suppose there are three regions -- L, M, R, and each region has two departments. The relationship of regional input and output is shown in Table 2. If the final demand is taken into consideration, the aggregate demand of the first department of region L shall be expressed by Equation 17.

$$X_1^L = Z_{11}^{LL} + Z_{12}^{LL} + Z_{11}^{LM} + Z_{12}^{LM} + Z_{11}^{LR} + Z_{12}^{LR} + Y_1^L \quad (17)$$

X_1^L denotes the output value of the first department of region L, Z_{ij}^{AB} denotes the amount of money used by j department of region B for the purchasing of products i produced in region A, and Y_1^L denotes the final demand of the first department of region L. The input coefficient can be expressed by Equation 18.

$$a_{ij}^{LL} = Z_{ij}^{LL} / X_j^L \quad (18)$$

Table 2 Input-output relationship among regions

		Intermediate demand department					
		L		M		R	
Intermediate input department		1	2	1	2	1	2
L	1	Z_{11}^{LL}	Z_{12}^{LL}	Z_{11}^{LM}	Z_{12}^{LM}	Z_{11}^{LR}	Z_{12}^{LR}
	2	Z_{21}^{LL}	Z_{22}^{LL}	Z_{21}^{LM}	Z_{22}^{LM}	Z_{21}^{LR}	Z_{22}^{LR}
M	1	Z_{11}^{ML}	Z_{12}^{ML}	Z_{11}^{MM}	Z_{12}^{MM}	Z_{11}^{MR}	Z_{12}^{MR}
	2	Z_{21}^{ML}	Z_{22}^{ML}	Z_{21}^{MM}	Z_{22}^{MM}	Z_{21}^{MR}	Z_{22}^{MR}
R	1	Z_{11}^{RL}	Z_{12}^{RL}	Z_{11}^{RM}	Z_{12}^{RM}	Z_{11}^{RR}	Z_{12}^{RR}
	2	Z_{21}^{RL}	Z_{22}^{RL}	Z_{21}^{RM}	Z_{22}^{RM}	Z_{21}^{RR}	Z_{22}^{RR}

The follow-up derivation process shall be as the illation process of Equation 3 and

Equation 4, and shall be showed in Equation 19 in the way of vetors:

$$(I - A)X = Y \tag{19}$$

wherein $A = \begin{bmatrix} a^{LL} & a^{LM} & a^{LR} \\ a^{ML} & a^{MM} & a^{MR} \\ a^{RL} & a^{RM} & a^{RR} \end{bmatrix}$, $X = \begin{bmatrix} X^L \\ X^M \\ X^R \end{bmatrix}$, $Y = \begin{bmatrix} Y^L \\ Y^M \\ Y^R \end{bmatrix}$

Equation 20 is processed through transpose, which is the same as Equation 7 above. Thus the reasoning process of the multi-regional model is in accordance with that of non-partitioned model. And the conception of Equation 21 shall be adopted to analyze the final demand change on each region.

$$X = (I - A)^{-1}Y \tag{20}$$

$$\Delta X = (I - A)^{-1}\Delta Y \tag{21}$$

3.5 Index of sensitivity and dispersion

Because of the damages to the buildings caused by earthquakes, the company cannot produce and provide products to the midstream and downstream companies successfully. Damages to the input capital of the departments of this kind shall affect the production of other production departments that use the products of these departments as raw materials. When the original input changes, the development of the midstream and downstream companies shall be affected, which forms a relationship called “index of forward linkage”. The outputs of such industries are mostly intermediate raw materials or services, such as petrochemical industry and supply of water and power. The index of forward linkage belongs to the supply side and can be calculated through analyzing the input-output model by supply-side model. The index of sensitivity can express the degree of forward linkage (Wang, 1986), and the calculation is as follows:

$$RF_i = \frac{1}{n}\sum_j b_{i\cdot} / \frac{1}{n^2}\sum_i \sum_j b_{ij} \tag{22}$$

The right-hand side of Equation 22 is the average of the elements in the row i of the IO table. When $RF_i > 1$, the level of forward linkage of i industry is higher than the average level of all the industries. When RFi < 1, vice versa.

Restoration and reconstruction shall mostly be performed for the earthquake damaged buildings. Vast demands shall be brought by the reconstruction to the construction industry, and building materials such as cement, steel and glass shall be purchased from the upstream by the construction department. Therefore, both the cement industry and the steel industry shall produce more products. When the production is expanded in response to the increase of final demand, the demand for raw materials shall also be increased and coherently the purchasing of raw materials from the upstream shall be increased. The degree of this relationship can be expressed by “index of backward linkage”. The index of backward linkage belongs to the demand side and can be calculated as index of dispersion (Wang, 1986), and the calculation is as follows:

$$RB_j = \frac{1}{n}\sum_i b_{\cdot\cdot j} / \frac{1}{n^2}\sum_i \sum_j b_{ij} \qquad (23)$$

The right-hand side of Equation 23 is the average of the elements in the Column j of the IO table. When $RB_j>1$, the level of backward linkage of j industry is higher than the average level of all the industries. When $RF_i<1$, vice versa..

4. Model for Regional Earthquake Economic Impact Analysis

The economic impacts from an earthquake includes the direct loss, the indirect loss (production loss) caused by damaged capitals and the repercussion effect (production loss of the self-industry and other industries). The direct loss includes casualties and damages of building structures, and the latter shall result in production loss and the demand of reconstruction. The analysis framework, range and methods of this research are shown in the figure 1. Repercussion effect caused by itself and other industry departments can be analyzed through the IO model after a single industry department is affected by disasters. The methods of analyzing the direct loss and the repercussion effect are introduced respectively as follows.

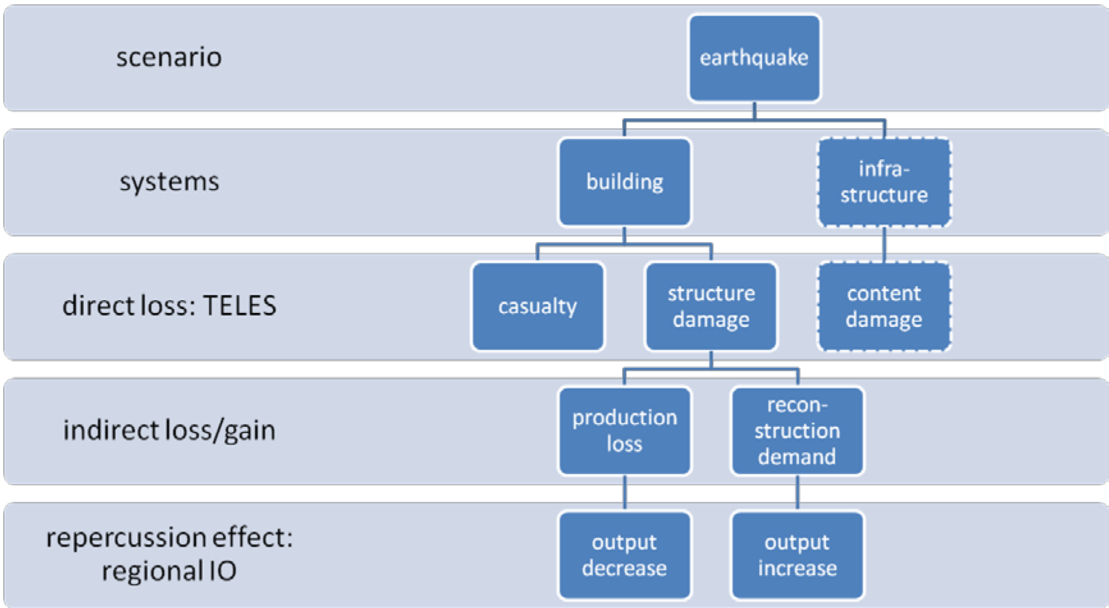


Figure 1 the framework of this research

Note: elements with dotted lines are not included in this research

4.1 Estimation on direct loss, demands for reconstruction and indirect loss

TELES (Taiwan Earthquake Loss Estimation System) is adopted in the research as the simulation tool of the direct loss of the earthquake. TELES was first introduced by National Science Council and the Department of Industrial Technology, Ministry of Economic Affairs, Taiwan, in 1998 from HAZUS - the American disaster loss estimation system - and called HAZ-Taiwan in which the local data of Taiwan are embedded. The program of HAZ-Taiwan was then rewritten by object programming language and the system was modularized by National Center for Research on Earthquake Engineering (NCREE), and called TELES. The system can stimulate the earthquake impacts on general buildings, infrastructure, transportation system and lifeline system, and estimate the casualties and loss caused by buildings. Because the database of the structures in Taiwan is not established completely, The TELES aims at the estimation on the casualties and direct loss caused by general buildings damages. Thus, the system cannot stimulate the direct and indirect loss caused by the interrupt of water, electric and transportation system.

The TELES divides the usage of buildings into 13 categories, which can be referred as buildings of 13 industries. The study does not calculate the loss of the contents in buildings. However, since the reconstruction period for structural damage of the buildings is usually longer than the period of repairing or replacement of contents in buildings. Therefore, we can estimate the indirect loss and production loss of the earthquake from the period of reconstruction of buildings. The production loss caused by the earthquake belongs to the impact from the supply-side. The TELES can stimulate the floor damage areas (DF) under various damage conditions (i) caused by a scenario earthquake. The period of reconstruction (RP) is defined in the TELES. We transferred the floor damage areas into production loss PL by following equation.

$$\mathrm{PL_j} = \left(\frac{\mathrm{GP_j}}{\mathrm{UF_j}}\right) * \sum_{\mathrm{i}} \left(\frac{\mathrm{RP_i}}{365}\right) * \mathrm{DF_i} \tag{24}$$

j is an industry in a certain region. GP is the annual gross output. UF is the floor areas used at the end of the year, and these two data are found in the Industry, Commerce and Service Census in 1995. For example, the production value per square meter of floor used by the manufacturing in northern area is $107.68 thousand NTD. As to the minor damage, the recovery (reconstruction) time is 5 days, and then the loss of production is $1.5 thousand NTD. As to the moderate, severe and complete damage, the recovery time is 30, 120 and 240 days respectively.

If all damaged buildings are reconstructed, it will increase of the final demand in construction department which belongs to impact from the demand-side. The TELES classifies the buildings structure into 15 categories. The reconstruction cost of each structure shall be different according to 4 different damage degrees. For example, the reconstruction cost of per square meter is $6000 NTD for the reinforced concrete structure with low-seismic design under complete damaged. If the damage is minor, the reconstruction cost of this structure is $60 NTD. If the damage is moderate, the reconstruction cost is $240 NTD. If the damage is severe, the reconstruction cost is $1920 NTD.

4.2 Estimation on Spread Effect

The TELES classifies buildings into 13 categories according to the purpose of buildings, but three of them including residence, public space and government agencies are not evaluated because these buildings cannot directly cause industrial production loss. The other 10 categories are amalgamated into 7 categories in order to coordinate with the industrial departments in the regional IO table. The floor damage areas of these 7 categories are treated as the external impact of the supply-side IO model. Damage to all the floors (13 categories) acquired reconstruction, which is regarded as the increase of the final demand of construction department.

Table 3 the adjustment of industrial departments

The usage of buildings in the TELES	Regional IO department after the adjustment	Original regional IO department
Agr1	Farming	Farming
Ind1	Manufacturing	the processing of the food, beverage and tobacco; textile, tailoring and garment accessories; leather products; timber and woodworks; paper, paper products, printing and publishing; chemical raw materials; artificial fiber; plastic products; other chemical products; petrochemicals; non-metallic ore products; steel; metallic products; other metals; machinery; household appliances; information and communication products; electronic accessories; electric motors and other electric machines; transportation tools; other products
Com1	Storage and retail trade	Storage, Communication and retail trade
Com2, Com3, Edu2	Food services and entertainment	Food service, Entertainment
Com4, Edu1	Education and human health	Education, Human health
Res2	Accommodation	Education, Human health
Rel1	Other services	Other services

The regional IO tables are estimated in Lin and Gao (2008). That is used to estimate the repercussion effects of production loss caused by building damage and the demands for reconstruction. The regional IO tables originally includes 46 departments. Beside departments in the third column of Table 3 are amalgamated with departments of TELES, the other 16 departments remain unchanged. The northern Taiwan area includes Taipei County/City, Keelung City, Taoyuan County, Hsinchu County/City, and Yilan County.

5. The Economic Impacts of Scenario Earthquakes in Northern Taiwan

This research sets two scenario earthquakes from the planning project

"Strengthening the Disaster Prevention and Rescue Abilities in Taipei County/City". In that project, in order to design a better disaster reduction plan, the distribution of the active faults in neighboring area and historical earthquakes are considered to set the place and scale of the potential earthquakes. Based on the building code amended in 2001, the scenario earthquakes are 475-year return period which is equivalent to the 10% exceeding probability within 50-year life time of a building. The peak ground acceleration of the corresponding buildings design is 0.23 g. Under such scale, several scenario earthquakes are simulated. Two scenario earthquakes which cause the largest direct loss (buildings structure loss), i.e., the demands for reconstruction are in active fault in Hsinchu and the swarms of earthquakes in Nan-ao. The comparison of the features and the results of the economic impacts of these two scenario earthquakes are shown in Table 4.

Table 4 Comparison table of the features and impacts of two scenario earthquakes

	Hsinchu Fault Earthquake	A Nan-ao Earthquake
Epicenter (longitude and latitude)	E121.88 N24.48	E121.08 N24.79
Magnitude	7.5	7.9
Depth (km)	10	7
Estimated casualties	934 (2.06)*	454
Damaged floor area (m^2)	35,127,297 (1.74)	20,136,722
Direct loss – buildings structure loss (million NTD)	18,460 (1.78)	10,368
Indirect loss –production loss of original industries (million NTD)	86,279 (1.94)	44,556
Repercussion effect of the production loss (million NTD)	280,211 (2.73)	102,859
Repercussion effect of the reconstruction demands (million NTD)	30,059 (1.79)	16,778

* The number in the brackets is the multiple of Hsinchu earthquake compared with Nan-ao earthquake

5.1 Overall Economic impacts

From the comparison of two scenario earthquakes shown in the Table 4, the scale of the Nan-ao earthquake is comparatively large. Because the epicenter of the Hsinchu earthquake is in inland, the data of various impacts is comparatively large. The damaged floor areas of the Hsinchu earthquake is 1.74 times of that of the Nan-ao earthquake and the multiple can be considered as the standard of comparison. The multiple of the estimated casualties is 2.06, which indicates that the population density of the buildings in the strong seismic area of the Hsinchu earthquake is higher than that of the Nan-ao earthquake. The multiple number of the original industrial production loss (1.94) is higher than that of the damaged floor areas, and this comparison indicates that the production activity of the buildings in the strong seismic area of the Hsinchu earthquakes is higher than that of the Nan-ao earthquakes. The multiple number of the repercussion effect loss (2.73) is higher than that of the damaged floor areas, and this comparison indicates that the repercussion effect of the industries in the strong seismic area of the Hsinchu earthquake is higher than that of the Nan-ao earthquake. Additionally, the repercussion effect of the production loss in the Hsinchu earthquake is 3.24 times of the original industrial production loss, but the repercussion effect of the production loss in the Nan-ao earthquake is 2.30 times of the original industrial production loss. Table 4 also indicates that the industries shocked by Hsinchu earthquakes have much more repercussion effect than that shocked by Nan-ao earthquake, which shall cause larger loss.

If all damaged buildings are reconstructed, the direct loss shall be the demands for reconstruction. The repercussion effects of reconstruction of two scenario earthquakes are both 1.6 times of the demands for reconstruction. The repercussion effect of the demands for reconstruction in the Hsinchu earthquake is 1.79 times of that in the Nan-ao earthquake, which is slightly higher than the multiple of the floor damaged areas, and indicates that the repercussion effect of the construction in the Hsinchu earthquake is larger than that in the Nan-ao earthquake. The reason may be that the buildings in the strong seismic area of the Hsinchu earthquake are more expensive than that of the Nan-ao earthquake.

5.3 Industrial impact analysis

The different shocks caused by the two scenario earthquakes shall have different impacts on the local industries, and the influenced local industries shall cause different repercussion effects because of industrial features. Table 5 shows the original industrial production loss of the two scenario earthquakes in northern Taiwan, and we can find that the percentages of the farming and manufacturing losses caused by the Hsinchu earthquakes are higher, and the percentages of the other five industries losses caused by the Nan-ao earthquakes are higher. But the main production loss of the two scenario earthquakes is in manufacturing, storage and retail trade, and food services and entertainment. Because of the characteristics of the IO analysis, the repercussion effect of a certain industry is fixed. The repercussion effects of three largest loss industries in the Hsinchu earthquakes are listed respectively (see Table 6). The repercussion effects of the manufacturing and storage and retail trade are mainly in northern Taiwan, and the reason is that there are more manufacturing in northern Taiwan, and many companies of the manufacturing are registered in northern Taiwan. The repercussion effects of the food services and entertainment are mainly in the central and southern Taiwan, and the repercussion effect in southern Taiwan is more than that in central Taiwan. The reason is that the upstream industry of the food services and entertainment is the farming which is mainly produced in the central and southern Taiwan.

Table 5 Table of original industrial production loss in the northern Taiwan caused by two scenario earthquake (million NTD)

	Hsinchu Earthquake		Nan-ao Earthquake	
Farming	130	0.16%	43	0.10%
Manufacturing	40,758	48.82%	13897	31.89%
Storage and retail trade	16,161	19.36%	9586	22.00%
Food services and entertainment	19,220	23.02%	15690	36.01%
Accommodation	433	0.52%	313	0.72%
Education and human health	5,698	6.82%	3193	7.33%
Other services	1,091	1.31%	850	1.95%
Total	83,491	100.00%	43,573	100.00%

Table 6 Production losses and repercussion effects in northern Taiwan caused by the Hsinchu Earthquakes (million NTD)

	Production loss of original industries	Repercussion effects of production losses				
		Northern	Central	Southern	Eastern	Total
Manufacturing	40,758	139,529 (57.04%)	43,714 (17.87%)	59,076 (24.15%)	2,296 (0.94%)	244,616
Storage and retail trade	16,161	9,780 (59.83%)	2,791 (17.07%)	3,611 (22.09%)	165 (1.01%)	16,346
Food services and entertainment	19,220	1,295 (20.31%)	2,125 (33.33%)	2,871 (45.04%)	83 (1.31%)	6,373

The repercussion effect of the manufacturing is 600.17% of the original production loss. That is 101.14% for storage and retail trade and 33.16% for food services and entertainment. This result shows that the manufacturing has high industrial linkage effect. The index of sensitivity (Equation 22) and dispersion (Equation 23) can express the industrial linkage effect. In Figure 2, the index of dispersion and sensitivity of all industries in northern Taiwan are divided into four quadrants for expression. Many manufacturing is in the first quadrant which indicates that the manufacturing has high forward and backward linkages. If the production of these industries is suspended, great impacts will be produced on many industries in the upstream and downstream. The retail trade is shown in the fourth quadrant. The index of dispersion is more than 1, but the index of sensitivity is less than 1. This indicates that this industry shall have more impact on downstream industries. The food services, entertainment, recreation and culture services, and storage and communication are all in the third quadrant, which indicates that the degree of industrial linkage is relatively small.

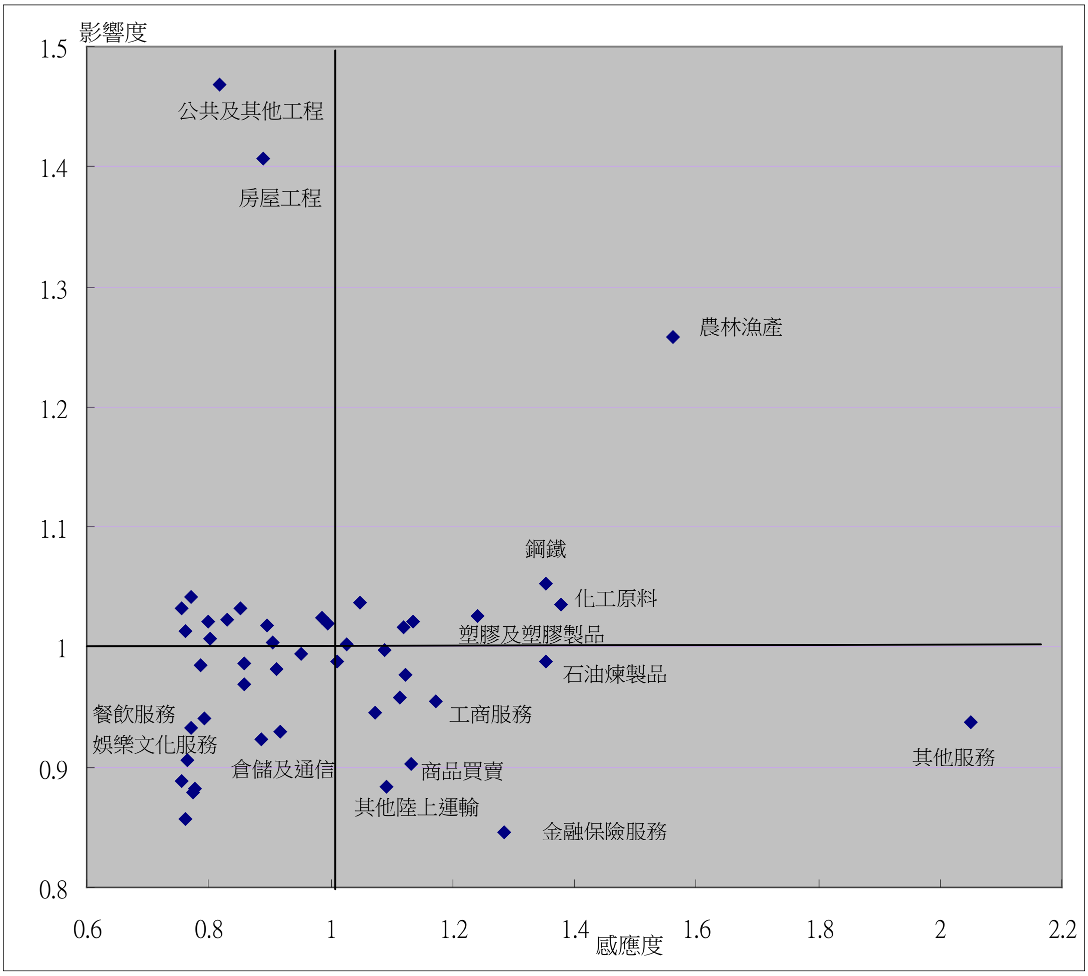


Figure 2 Figure of industrial linkage index in the Northern Taiwan

The overall impacts of disasters on the industry can be expressed by the output effect, which includes the production loss of the original industry caused by direct loss and the repercussion effect on itself and other industries. According to the output effects of the production losses and the reconstruction demands of the two scenario earthquakes, the top five industries of the largest gain/loss are listed in Table 7. The sequences of the top five industries concerning the production loss in the two earthquakes are slightly different. The loss of food services and entertainment, and storage and retail trade caused by Nan-ao earthquake is relatively larger. To sum up, although the construction department has huge loss, it will be benefited from reconstruction demands. Therefore, the industries affected the most by the earthquake in the northern Taiwan are the manufacturing, food services and entertainment, storage and retail trade, and public and construction, for which the strategy of disaster reduction shall be sketched out.

Table 7 the output effects comparison table of the top five industries in the Northern Taiwan (million NTD)

Output effect of production loss caused by Hsincheng earthquake		Output effect of production loss caused by Nan-ao earthquake	
Manufacturing	55,203	Manufacturing	19,017
Construction	27,942	Food services and entertainment	17,645
Food services and entertainment	24,770	Storage and retail trade	10,719
Public and construction	23,734	Construction	9,976
Storage and retail trade	18,991	Public and construction	8,517
Output effect of reconstruction demands caused by Hsincheng earthquake		Output effect of reconstruction demands caused by Nan-ao earthquake	
Construction	18,281	Construction	10,424
Real estate services	1,102	Real estate services	628
Manufacturing	881	Manufacturing	502
Public and construction	458	Public and construction	261
Farming	350	Farming	199

6. Conclusions

By simulating two scenario earthquakes - Hsincheng Earthquake and Nan-ao Earthquake, which may cause major disaster to the northern Taiwan, this study estimates the damages to the building structure caused by the earthquake, and analyzes the economic impacts on the production loss and reconstruction demands. The result found is that all kinds of losses caused by Hsincheng earthquake are larger than that caused by Nan-ao earthquake. Hsincheng earthquake is the main scenario considered in the future plan for disaster reduction. The reason why the Hsincheng earthquake caused a greater loss is that the strong seismic area lies in Hsinchu, where the local buildings are mainly for manufacturing. The output value and the repercussion effect are both higher than that of the Nao-ao earthquake. Among the top five industries which have relatively great earthquake loss in the northern Taiwan, the construction department has huge loss, but the demand of reconstruction will also spur the corresponding output value. Therefore, the industries affected the most are the manufacturing, food services and entertainment, storage and retail trade, public and construction. Compared with the sequence of top five industries, the Nan-ao earthquake brought more loss in the storage and retail trade, and food services and entertainment, most of which lie their repercussion effects on central and southern Taiwan. The upstream of food services and entertainment is mainly farming, of which the production mainly lies in the central and southern Taiwan.

The loss in the manufacturing caused by the earthquake in the northern region is huge, and the industrial linkage effect is significant. Therefore, the government shall give first rank to encourage the manufacturing to carry out the disaster reduction, such as seismic retrofit, or seismic evaluation which can prompt the manufacturing to conduct the disaster reduction voluntarily. The loss of the food services and entertainment and storage and retail trade are also huge. Besides the disaster reduction, there is a measure to reduce the agriculture affected, due to the fact that the repercussion effect mainly lies in the farming in the southern-central Taiwan. The government can purchase agricultural products after disaster and transfer to seismic area, which can relieve the people in the area and reduce the repercussion effect on farming department.

This study only discusses the impacts caused by the structural damages to the buildings after earthquake, and the casualties and the damages to the residence will have enormous impacts on the society. The damages to the water, electricity and transportation system caused by the earthquake are also important sources of production loss, but those are not considered in this research. If there are analyses of the disaster vulnerability of infrastructures, they can be brought into the economic impact simulation. The IO analysis adopted in this study has the properties such as the production has constant returns to scale, and the inputs of production cannot be replaced, etc. Therefore, the disaster mitigation such as transfer production time, replacement of inputs, and resources allocation by price mechanism cannot be estimated. Moreover, the economic impacts in this study are the most serious situation.

References

Boarnet, M.G., 1998. Business Losses, Transportation Damage and the Northridge Earthquake. *Journal of Transportation and Statistics*, 1(2).

Breaden, J.P., 1973. The Generation of Flood Damage Time Sequences, *University of Kentucky Water Resources Institute Paper*, 32.

Cho, S., Gordon, P., II, J.E.M., Richardson, H.W., Shinozuka, M. and Chang, S., 2001. Integrating Transportation Network and Regional Economic Models to Estimate the Costs of a Large Urban Earthquake, *Journal of Regional Science*, 41, 39-65.

Cochrane, H.C., 2004. Indirect Losses from Natural Disasters: Measurement and Myth, in: Okuyama, Y. and Chang, S.E. (Eds.), *Modeling Spatial and Economic Impacts of Disasters*, 37-52, New York: Springer.

Ellson, R.W., Milliman, J.W. and Roberts, R.B., 1984. Measuring the Regional Economic Effects of Earthquakes and Earthquake Predictions, *Journal of Regional Science*, 24, 559-579.

Grigg, N.S. and Helweg, O.J., 1975. State-of-the Art of Estimating Flood Damage in Urban Areas. *Journal of the American Water Resources Association*, 11, 379-390.

Hicks, J. R., 1946. *Value and Capital: An Inquiry into Some Fundamental Principals of Economic Theory*. Oxford: Clarendon Press.

Hsiao, D.J., Huang, H.H., Hong, M.C., Lu, M.M., Luo, Y.L., 2007. Risk Analysis of Loss Probability of Flood Disaster in Freshwater River Basin, *Taiwan Economic Forecast and Policy*, 37(3), 31-53.

Kates, R. W., 1965. Industrial Flood Losses: Damage Estimation in the Lehigh Valley, University of Chicago, *Water Resource Paper*, 98, University of Chicago Press.

Lin, H.J., Gao, C.M., 2008. Effect Analysis on Regional Economy in the Construction period and after the opening of traffic on Suhua National Road, *Taiwan Economic Forecast and Policy*, 38, 2, 31-72.

Luo, J.H., Yeh, C.H., Chen, L.C., Hong, H.C., Chian, W.Y., Liao, W.Y., 2002. HAZ-TaiwanEvaluation System of Losses Caused by Seismic Disasters, *NTU Engineering*, 85, 13-32.

Miller, R. E. and P. D. Blair, 1985. *Input-Output Analysis: Foundations and Extensions*, Englewood Cliffs, New Jersy: Prentice Hall Professional.

Okuyama, Y., Hewings, G.J.D. and Sonis, M., 1999. Economic Impacts of an Unscheduled, Disruptive Event: a Miyazawa Multiplier Analysis, in: Hewings, G.J.D., Sonis, M., Madden, M. and Kimura, Y. (Eds.), *Understanding and Interpreting Economic Structure*, Heidelberg: Springer, 113-144, New York: Springer.

Okuyama, Y., Hewings, G.J.D. and Sonis, M., 2004. Measuring Economic impacts of disasters: Interregional Input-Output Analysis Using Sequential Interindustry Model, in: Okuyama, Y. and Chang, S. E. (Eds.), *Modeling Spatial and Economic Impacts of Disasters*, 77-101, New York: Springer.

Parker, D. J., Green, C.H. and Thompson, P. M., 1987. *Urban Flood Protection Benefits - a Project Appraisal Guide*. Aldershot, England: Gower Technical Press.

Research center of Comprehensive Disaster in Taiwan University and Taipei Government, 2004. Strengthening the Disaster Prevention and Rescue Abilities in Taipei County/City – the disaster prevention and rescue promoted by the cooperation of Taipei Government and Taiwan University, special report of the National Science and Technology Center for Disaster Reduction, Taipei: National Science and Technology Center for Disaster Reduction.

Rose, A. and Guha, G., 2004. Computable General Equilibrium Modeling of Electric Utility Lifeline Losses from Earthquakes, in: Okuyama, Y. and Chang, S.E. (Eds.), *Modeling Spatial and Economic Impacts of Disasters*, 37-52, New York: Springer.

Rose, A., 2004. Economic Principles, Issues, and Research Priorities in Hazard Loss Estimation, in: Okuyama, Y. and Chang, S.E. (Eds.), *Modeling Spatial and Economic Impacts of Disasters*, 13-36, New York: Springer,.

Rose, A., Benavides, J., Chang, S.E., Szczesniak, P. and Lim, D., 1997. The Regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions, *Journal of Regional Science*, 37, 437-458.

Smith, D.J.G. and Viljoen, M.F., 1981. 'Guidelines for Assessing Flood Damage in South Africa', in, Pretoria, South Africa: Water Research Commission in collaboration with the University of the Orange Free State, Bloemfontein,

Institute of Social and Economic Research (ISER) and the University of Stellenbosch, Stellenbosch, Bureau for Economic Research.
United Nations Economic Commission for Latin America and the Caribbean, UNECLAC, 2003. *Handbook for Estimating the Socio-Economic and Environmental Effects of Disasters*.
Van der Veen, A. and Logtmeijer, C., 2005. Economic Hotspots: Visualizing Vulnerability to Flooding, *Natural Hazards*, 36, 65-80.
Wang, T.F., 1986. Input-output Analysis and Application - Empirical Study in Taiwan, *Journal of the Bank of Taiwan*, 37(1), 186-218.
Wang, T.F., He, L.C., 1994. Comparative Studies of Noncensus Estimation Method of Regional Input Coefficient, *Collected Papers of Annual Meeting of Taiwan Economic Association 1994*: 83-122.
Werling, J. and Horst, R., 2009. Macroeconomic and Industry Impacts of 9/11: An Interindustry Macroeconomic Approach, Peace Economics, *Peace Science and Public Policy*, 15, Article 5.
White, G.F., 1945. *Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States*. Department of Geography, University of Chicago Research Paper No. 29, Chicago.
Wu, Y.W., 2003. *Analysis on Economic Impact of Tourist Resources Reconstruction in the Central Region in Taiwan after the Sep. 21 Earthquake.*, master’s thesis, Graduate Institute of Forestry, National Taiwan University.
Yamano, N., Yoshio, K. and Yoshiharu, S., 2007. Modeling the Regional Economic Loss of Natural Disasters: The Search for Economic Hotspots. *Economic Systems Research*, 19, 163-181.

Effectiveness of the economic compensation for living near a nuclear power station: A comparison before and after a large earthquake shock

Takaki Kato[1], Shogo Takahara[2], Toshimitsu Homma[2]

Abstract

A survey was conducted in a neighboring area of a Japanese nuclear power station before and after a severe earthquake shock in 2007. The earthquake affected the cognition of local people to both the merits and demerits of hosting Kashiwazaki-Kariwa Nuclear Power Station (KKNPS). The earthquake led to positive cognitions among the local people toward the merits. After the earthquake, more people became aware of the risk and inconveniences during the normal operation of the power station, but no increase was detected in the proportion of people who were worried about accidents. A unit of economic incentive after the earthquake was at least as effective as before as a compensation for the demerits of hosting this power station in the area surveyed.

1. Introduction

This paper investigates whether economic incentive provided to areas located near a nuclear power station in Japan effectively compensates for the nuclear risk perceived by the residents in these areas. A substantial amount of economic incentive is provided to such areas in terms of tax revenues from the owner company of the power station and subsidies from the central government. Knowing the response of people to this economic incentive is significant when considering the future of nuclear energy. In particular, cost benefit analyses (CBA) of nuclear power need, as an element of their cost calculation, information on the amount of money required to compensate for the nuclear risk among local communities. However, we are not quite convinced that money can compensate for such a potentially catastrophic risk. Moreover, we are not certain as to how the views of local people on compensation are affected by events that highlight nuclear safety.

Money metric measurement of health risk is a central issue of nuclear power CBA. Most studies have placed great emphasis on the objective risk estimates of engineering studies (European Commission, 1995; OECD, 2003). For example, the European Commission (1995) used scientific estimates of the number of probabilistic

[1]University of Kitakyushu
1-1 Hibikino, Wakamatsu, Kitakyushu, 808-0135 Fukuoka, Japan
Email: tkato@env.kitakyu-u.ac.jp
[2]Japan Atomic Energy Agency

deaths due to nuclear reactor accidents and translated them into money values using a value of statistical life (VSL)[3]. The study was part of a program that compared social costs among various energy sources; the same VSL was applied to all the energy source evaluations. These studies do not fully consider people's cognition of nuclear risks[4]. Therefore, it is not clear how closely these estimates approximated the correct CBA measure of the cost that is either willingness to accept compensation (WTA) for enduring a nuclear risk or willingness to pay (WTP) for avoiding a nuclear risk. Another disadvantage of the engineering-based approach is its lack of sensitivity in reflecting the changes in people's views over time.

Stated preference methods such as contingent valuation (CV) and choice experiments (CE) are frequently used for WTA/WTP estimates. These methods greatly rely upon people's cognition on the issues in question. So far, only a few studies have focused on nuclear issues (Itaoka et al., 2006; Riddel and Schwer, 2006; Riddel, and Shaw, 2003). We need further empirical knowledge on the effectiveness of economic compensation. In addition, we need to eliminate potential biases caused by hypothetical questions used for stated preference methods (Murphy et al., 2005; Brown et al., 1996).

A survey conducted on the people living near Kashiwazaki-Kariwa Nuclear Power Station (KKNPS) located in Niigata Prefecture, Japan, who experienced the largest earthquake ever to hit a nuclear power station, should provide a clue for the questions regarding the compensation for a nuclear risk. The powerful Niigataken-Chuetsuoki Earthquake of magnitude 6.8 hit the area on July 16, 2007. It killed 15 individuals, injured 2,315 individuals, and destroyed 1,319 houses. KKNPS was also affected by the earthquake. The mass media aired impressive footage of black smoke rising from one of the transformers of KKNPS throughout the country. Seven nuclear reactors of KKNPS were safely shut down immediately after the earthquake. There were leakages of reportedly non-health-threatening amounts of radioactive substances from the power station to the sea and the air due to the earthquake.

In addition to the experience of the earthquake, these districts are ideal as a case-study site for the effectiveness of economic compensation for nuclear risk. Approximately 90% of the population of the three districts adjacent to KKNPS lives within a 10-km radius from the power station. This circular area corresponds to the emergency planning zone in case of a nuclear accident. Perceived health-risk levels in

---

[3]Nordhous (1997) summarizes health risk estimates based on similar estimation procedures.

[4]Disaster aversion can be a factor in the possible gap between the objective and perception-based estimates of life and health costs. Eeckhoudt et al. (2000) and Pearce (2001) have reviewed this topic.

the three districts are similar to one other, as shown later, whereas the amount of per capita economic incentive provided to each district differs largely among the districts. This geographical characteristic allows us to compare people's responses to different amounts of economic compensation while approximately maintaining the same cognitive risk level. It is noteworthy that the amounts of economic compensation are real amounts unlike CV/CE questions, where respondents are presented with hypothetical amounts of economic compensation.

2. Data

Our survey location is the neighborhood area surrounding KKNPS, located approximately 210 km north-northwest of Tokyo. KKNPS's first reactor unit started its commercial operation in 1985; presently, it has seven reactors. The power station is operated by a private company, and it sends electricity to Tokyo and its suburbs. Therefore, the station's neighborhood area does not receive the benefits of electricity supply from this power station. This characteristic is suited for the current study because it simplifies the components of compensation for the risk of living there.

This study analyzes the results of social surveys of the three districts in the neighborhood area of KKNPS: Kariwa, Kashiwazaki, and Nishiyama. The total population of the districts was 98,000 in 2005. The three districts were surveyed in both November 2005 and March 2010. During the 2005 survey, KKNPS was operated normally with five of its seven reactors being active, while two reactors were shut down for periodic maintenance. KKNPS had shut down all its reactors for two years after the 2007 earthquake. At the time of the 2010 survey, two reactors had been restarted and the remaining five were under review for possible earthquake damages.

The survey questionnaires consisted of four parts. The first part asked questions regarding the merits and demerits of hosting KKNPS in the area. The second part included questions on whether the current size of economic incentive in each district was adequate for compensating for the risk of living near KKNPS. The third part consisted of questions on the perceptions of the risk of and countermeasures for nuclear accidents. The fourth part included questions on the personal attributes of the respondents. Many of the questions were common to the 2005 and 2010 surveys.

In the 2005 survey, mailed a questionnaire was mailed to 1,400 randomly chosen adults and 616 responses were collected; the response ratio was 44%. In the 2010 survey, a questionnaire was mailed to 1,500 randomly chosen adults and 827 responses were collected; the response ratio was 55%. Table 1 summarizes the effective sample sizes for each district for each year. Table 2 summarizes the personal attributes for the two surveys. The last right-hand column lists the p-values of t-tests that compared the mean values between the two survey years for each district and attribute. For most attributes, there is no large difference between the survey years. The exceptions are gender ratio for Nishiyama and age and household income for Kariwa. Each of these was recognized by a t-test to be different between the survey years at the 5% significance level. Among the 2010 survey respondents, 91% had experienced the 2007 earthquake.

Table 1. Sample sizes

	2005	2009	Sum
Kariwa	128	187	315
Kashiwazaki	320	435	755
Nishiyama	168	205	373
Sum	616	827	1443

Table 2. Mean values of personal attributes

		2005		2010		P value
		Mean	SE	Mean	SE	
Gender (male=1, female=0)	Kariwa	0.45	0.044	0.50	0.037	0.401
	Kashiwazaki	0.48	0.028	0.45	0.024	0.392
	Nishiyama	0.42	0.038	0.59	0.035	0.001
Age	Kariwa	45.7	1.04	52.0	0.90	0.001
	Kashiwazaki	48.6	0.82	49.5	0.70	0.441
	Nishiyama	50.4	1.05	50.6	1.04	0.896
Household income	Kariwa	773	39.6	623	26.7	0.001
	Kashiwazaki	547	19.2	560	15.5	0.627
	Nishiyama	580	28.4	578	23.1	0.957
Nuclear/electricity job	Kariwa	0.18	0.034	0.26	0.032	0.101
	Kashiwazaki	0.14	0.019	0.14	0.017	0.844
	Nishiyama	0.08	0.021	0.12	0.023	0.219

3. Results and discussion

3.1 Cognition of merits and demerits of hosting KKNPS

We proposed six options as the possible merits of hosting KKNPS in the area and asked the respondents to choose all the options that described their views. Table 3 summarizes the answers. The last right-hand column lists the results of t-tests that compared the values obtained in 2005 and 2010. At the 5% significance level, results for 7 out of 18 rows in the table show statistically significant differences. In all seven rows, the merits of hosting KKNPS are better admitted in 2010 than in 2005. In addition, for most of the remaining rows, the cognitions of merits are more positive in 2010 than in 2005. Therefore, the 2007 earthquake led to positive cognition of the merits of KKNPS among the local people. At least, the earthquake did not lead to a reduction in the proportion of people who admitted these merits.

We proposed four options as the possible demerits of hosting KKNPS and again asked the respondents to choose all the options that described their views. Table 4 summarizes the answers. The cognition of "Risk of accidents" did not change before and after the earthquake for all three districts, whereas that of "Radiation exposure at normal operation" and "Other inconveniences" showed an increasing tendency after the earthquake. In particular, changes in cognition of the following demerits were statistically significant at the 5% level: "Radiation exposure at normal operation" in Kariwa and "Other inconveniences" in both Kariwa and Nishiyama. "Other inconveniences" may include damages to local tourism and others. Therefore, the earthquake made more people aware of the demerits during normal operation but not of the risk of accidents.

Table 3. Merits of hosting KKNPS

		2005		2010		P value
		Mean	SE	Mean	SE	
Job opportunity	Kariwa	0.31	0.041	0.34	0.035	0.529
	Kashiwazaki	0.17	0.021	0.22	0.020	0.054
	Nishiyama	0.16	0.028	0.23	0.030	0.090
Reduced electricity bill	Kariwa	0.38	0.043	0.54	0.037	0.005
	Kashiwazaki	0.44	0.028	0.56	0.024	0.002
	Nishiyama	0.49	0.039	0.55	0.035	0.243
Good public welfare services	Kariwa	0.48	0.044	0.32	0.037	0.248
	Kashiwazaki	0.26	0.025	0.45	0.024	0.001
	Nishiyama	0.29	0.035	0.44	0.035	0.003
Good public facilities	Kariwa	0.58	0.044	0.53	0.037	0.372
	Kashiwazaki	0.24	0.024	0.27	0.021	0.345
	Nishiyama	0.36	0.037	0.31	0.032	0.326
Moral as primary electricity supplier area	Kariwa	0.16	0.032	0.26	0.032	0.026
	Kashiwazaki	0.18	0.021	0.20	0.019	0.379
	Nishiyama	0.14	0.027	0.21	0.029	0.059
No merits	Kariwa	0.16	0.033	0.15	0.026	0.649
	Kashiwazaki	0.36	0.027	0.17	0.018	0.001
	Nishiyama	0.35	0.037	0.20	0.028	0.001

Table 4. Demerits of hosting KKNPS

		2005		2010		P value
		Mean	SE	Mean	SE	
Radiation exposure at normal operation	Kariwa	0.19	0.035	0.32	0.034	0.008
	Kashiwazaki	0.17	0.021	0.20	0.019	0.267
	Nishiyama	0.20	0.031	0.22	0.029	0.587
Risk of accidents	Kariwa	0.73	0.039	0.74	0.032	0.966
	Kashiwazaki	0.79	0.023	0.78	0.020	0.765
	Nishiyama	0.89	0.025	0.87	0.024	0.585
Other inconveniences	Kariwa	0.01	0.008	0.06	0.018	0.004
	Kashiwazaki	0.03	0.009	0.04	0.009	0.501
	Nishiyama	0.03	0.013	0.08	0.019	0.023
No demerits	Kariwa	0.23	0.037	0.19	0.029	0.414
	Kashiwazaki	0.19	0.022	0.16	0.018	0.283
	Nishiyama	0.14	0.027	0.11	0.022	0.384

An additional question was asked about the health risk to the respondents and their families in case of a potential accident in KKNPS. A majority of people were aware of such a risk. The proportion of respondents who perceived the health risk was 84%, 78%, and 82% in 2005 and 81%, 80%, and 84% in 2010 for Kariwa, Kashiwazaki, and Nishiyama, respectively. The proportion did not change statistically significantly before and after the earthquake for each of the three districts, with p-values from t-tests being 0.512, 0.683, and 0.620 for Kariwa, Kashiwazaki, and Nishiyama, respectively. There was no clear difference in the cognition of the health risk across the three districts for each year, with the results from chi-square tests being $\chi^2(2) = 1.94$, p = 0.379 for the 2005 survey and $\chi^2(2) = 1.72$, p = 0.424 for the 2010 survey.

3.3 Acceptance of economic compensation

Economic incentives are provided to the three districts for hosting KKNPS. The largest source of the economic incentives is the property tax from KKNPS. In addition, there are the other tax revenues from the owner company of KKNPS and various incomes of subsidies from the central government. Most of the economic incentives are provided to local governments and used as a part of public expenditures. Only a fraction is directly paid to the individuals as a subsidy for electricity bills.

The respondents were presented with the per capita amount of the total economic incentives of their own district at the time of survey and then asked whether that amount was adequate compensation for the demerits of hosting KKNPS. The answers were elicited on a five-degree scale: “Agree,” “Rather agree,” “Neither agree nor disagree,” “Rather disagree,” and “Disagree.” Table 5 shows the results for both 2005 and 2010 surveys.

Table 5 shows that at least, the earthquake did not decrease the proportion of people who considered that the amount of economic incentive provided to their district could compensate for the nuclear risk of KKNPS. We focus on the proportion of “compensated” respondents, which is defined as the sum of the number of respondents who chose either “Agree” or “Rather agree” in response to this question. In Kariwa, the proportion of “compensated” respondents was 30% in 2005. This became 32% in 2010, although Kariwa faced a substantial reduction in the annual per capita economic incentive from 709,000 yen in 2005 to 601,000 yen in 2009. Kashiwazaki showed a sharp increase in the proportion of “compensated” respondents from 21% to 34% ($p = 0.001$ by t-test) between the two surveys, whereas its economic incentive only slightly increased from 109,000 yen to 116,000 yen during the same period. Nishiyama’s result is indeterminable because this district saw sharp simultaneous increases both in the proportion of “compensated” respondents (from 18% to 34%; $p = 0.001$) and economic incentive (from 28,000 yen to 116,000 yen) during this period. Given the tendency of an increase after the earthquake in the proportion of people being aware of the demerits of KKNPS, a unit of economic incentive after the earthquake was at least as effective as before as a compensation for the demerits.

It is noteworthy that before the earthquake, a larger per capita amount of economic incentive in a district resulted in a larger share of “compensated” respondents there. However, this positive correlation between the economic incentive size and the share of “compensated” respondents was not observed after the earthquake.

Table 5. Acceptance of economic compensation

		Agree	Rather agree	Neither agree nor disagree	Rather disagree	Disagree	Total
2005	Kariwa	13	24	41	21	24	123
		10.6%	19.5%	33.3%	17.1%	19.5%	100.0%
	Kashiwazaki	28	35	106	60	74	303
		9.2%	11.6%	35.0%	19.8%	24.4%	100.0%
	Nishiyama	11	18	65	37	32	163
		6.7%	11.0%	39.9%	22.7%	19.6%	100.0%
2009	Kariwa	20	38	55	36	32	181
		11.0%	21.0%	30.4%	19.9%	17.7%	100.0%
	Kashiwazaki	70	76	149	82	50	427
		16.4%	17.8%	34.9%	19.2%	11.7%	100.0%
	Nishiyama	39	28	67	42	23	199
		19.6%	14.1%	33.7%	21.1%	11.6%	100.0%

3.4 Ordered logit regression of the acceptance of economic compensation

Table 6 shows the results of ordered logit regressions of the 2005 and 2010 datasets. The dependent variable was the degree of accepting economic compensation; the summary of this is shown in Table 5. Independent variables were under two categories: threshold values and slope coefficients. Slope coefficients included per capita economic incentive, dummy variables indicating an agreement to various merits and demerits of hosting KKNPS, gender, age, household income, and a dummy variable indicating a household involving at least one nuclear/electricity worker. At the 5% significance level, admitting KKNPS's contribution to "Good public welfare services" or "Moral as primary electricity supplier area" or being a member of households with a nuclear/electricity worker were factors for accepting economic compensation in the 2005 survey. Because there was no statistically significant variable for the 2010 survey, the factors for accepting economic compensation became unclear after the earthquake.

Table 6. Ordered logit regression

Variable		2005		2010	
		Coefficient	P-value	Coefficient	P-value
Threshold	α1	-1.272	0.005	-1.962	0.000
	α2	-0.158	0.726	-0.769	0.027
	α3	1.482	0.001	0.622	0.073
	α4	2.637	0.000	1.606	0.000
Slope	Per-capita Economic incentive	0.001	0.102	-0.001	0.078
	Job opportunity	-0.217	0.350	-0.078	0.648
	Reduced electricity bill	0.138	0.423	0.101	0.463
	Good public welfare services	0.679	0.001	0.066	0.656
	Good public facilities	0.268	0.158	-0.119	0.441
	Moral as primary electricity supplier area	0.491	0.037	0.177	0.282
	Radiation exposure at normal operation	-0.310	0.177	0.131	0.416
	Risk of accidents	-0.284	0.211	-0.155	0.384
	Other inconveniences	-0.409	0.450	0.241	0.412
	Gender	-0.110	0.519	0.032	0.811
	Age	-0.003	0.691	0.004	0.477
	Household income	0.000	0.826	0.000	0.502
	Nuclear/electricity job	0.768	0.005	-0.089	0.667
	Sample size	475		742	
	Pseud-R^2	0.035		0.004	

4. Conclusion

The 2007 earthquake affected cognitions of both the merits and demerits of KKNPS. The earthquake led to positive cognitions of the merits of KKNPS among the local people. After the earthquake, more people became aware of the risk and inconveniences during the normal operation of the power station, but no increase was detected in the proportion of people who were worried about accidents in the power station. Before the earthquake, economic incentives compensated 18%–30% of the respondents for the demerits of hosting KKNPS and a positive correlation was present between these percentages and the amount of per capita economic incentive provided to each district. After the earthquake, the percentages of compensated respondents became around 30% throughout the three districts. A unit of economic incentive after the earthquake was at least as effective as before as a compensation for the demerits of hosting KKNPS. Before the earthquake, some of the personal attributes and views of respondents on KKNPS led to an increase in the acceptance of the economic compensation, but the impact of these factors became unclear after the earthquake.

Acknowledgements:
The authors are grateful to Dr. Shiro Matsumoto and Mr. Masahisa Hatta for their indispensable help for the 2005 survey and Prof. Masashi Nishikawa for providing information on the amounts of the economic incentives provided to the area surveyed.

References:

Brown, T.C., Champ, P.A., Bishop, R.C., McCollum, D.W. (1996) Which response format reveals the truth about donations to a public good? Land Economics, 72(2), 152-166.

Eeckhoudt, L., Schieber, C., and Schneider, T. (2000) Risk aversion and the external cost of a nuclear accident. Journal of Environmental Management, 58(2), 109-117.

European Commission (1995) ExternE: Externality of Energy: Vol.5 Nuclear. European Commission.

Itaoka, K., Saito, A., Krupnick, A., Adamowicz, W., Taniguchi, T. (2006) The effect of risk characteristics on the willingness to pay for mortality risk reductions from electric power generation. Environmental and Resource Economics, 33(3), 371-398.

Murphy, J.J., Stevens, T.H., Weatherhead, D. (2005) Is cheap talk effective at eliminating hypothetical bias in a provision point mechanism? Environmental and Resource Economics, 30(3), 327-343.

Nordhaus, W.D. (1997) Swedish Nuclear Dilemma: Energy and Environment. Resources for the Future, Washington, D.C.; USA.

OECD (2003) Nuclear Electricity Generation: What Are the External Costs? Nuclear Energy Agency, OECD.

Pearce, D. (2001) Energy policy and externalities: An overview. Paper prepared for OECD Nuclear Energy Agency Keynote Address to Workshop on Energy Policy and Externalities: The Life Cycle Analysis Approach, Paris, November 15-16, 2001.

Riddel, M., and Shaw, W.D. (2003) Option wealth and bequest values: The value of protecting future generations from the health risks of nuclear waste storage. Land Economics, 79(4), 537-548.

Riddel, M., and Schwer, R.K. (2006) Winners, losers, and the nuclear-waste dilemma. Environmental and Resource Economics, 34(2), 317-338.

Analysis of Elasticities of Household Demand for Water in Beijing[1]

Ma Xunzhou[2]， Zhang Shiqiu[3]， Xie Xunxuan[4]， Yue Peng， Deng Liangchun

College of Environmental Science and Engineering , Peking University , Beijing 100871

Corresponding Author Zhang Shiqiu， E-mail zhangshq@pku.edu.cn

【**Abstract**】Because of current situation in water scarcity and the variety of problems in water resource supply management, the function of water resource demand management policy is increasingly put into effect. The policy of water pricing as that of demand management is widely concerned.

Establishment and adjustment of household water price concerned is always the problem on public policy. On the one hand, raising pirce can redound to improvement on household behavior and efficiency of water use. On the other hand, as the water is characterized as necessity of life, the issue on equality of water price adjustment becomes a key factor in water price reform. Hence, the degrees of sensibility to the change in price and income in different income groups need to be fully aware of to lay the foundation for the research on efficiency and equality in water pricing policy.

This paper analysed the effect taken by the changes in water price and income on household water demand in different income groups through identification of the key factors affecting household water demand. Based on the references on household

[1] This paper is draft based on the research of Income Related Incidence of the Welfare Impacts of Water Pricing,2005,Study is now still in progress with uncertainties,please do not quote.

[2] Ma xunzhou:Ph.D in Environmental Economics and Policy.Environment and Economy institute,College of Environmental Science and Engineering,Peking University.Email Adress: runzede@163.com.

[3] Zhang shiqiu:Professor in Environmental Economics and Policy. Environment and Economy institute,College of Environmental Science and Engineering,Peking University.Email Adress: zhangshq@pku.edu.cn.

Xie xunxuan:Ph.D in Environmental Economics and Policy.Environment and Economy institute,College of Environmental Science and Engineering,Peking University.Email Adress: xxx@pku.edu.cn.

[4] Xie xunxuan:Ph.D in Environmental Economics and Policy.Environment and Economy institute,College of Environmental Science and Engineering,Peking University.Email Adress: xxx@pku.edu.cn.

water demand,this paper firstly identified main factors on demand.By different econometric measures to obtain the consistency estimators,this paper then estimated the income and price elasticities of different income groups based on almost ideal demand system.Lastly,comparative analysis of elasticities of different income groups was presented to understand the impact on the different income groups and the responsive degrees of them.

【Key Words】Water Demand;Income Group;Price Elasticity;Income Elasticity

1 Background

Because of problems on scarcity and supply management of water resource,the role of demand management policy becomes increasingly important and pricing policy as demand management instrument draws wide attention.

The pricing policy of household water is always widely concerned in public policy. Behavior of household on water use can be improved by raising water price on the one hand and issue on equity of water price adjustment should be concerned as an significant factor on water price reform on the other hand because of attribute of water as a necessity.It is important to have full realization on how the changes of price and income affect water demand of different income groups to lay a foundation for research on efficiency and equity of water pricing policy.

This paper analysed the effect on water demand of different income groups by changes of water price and income on the basis of determinants identification of household water demand.Price and income elasticities and other coefficients were estimated by AIDS model and impacts on different income groups by changes of price and income based on price and income elasticities comparatively analysed.

2 Literatures

Henry S.Foster,Jr and Bruce R.Beattie(1979)[1]established household water demand function including such determinants as population density, seasons and districts to estimate price and income elasticities in different districts of USA based on the classic consumer demand theory. The result showed price and income elasticities respectively were -1.27 and 0.4619 and coefficients of population density and rainfall respectively were 0.4345 and -1.679; Panos Pashardes, Phoebe Koundouri and Soteroula Hajispyrou(2001)[2] analysed household water demand of different income groups based on AIDS model in Cyprus. The results presented income elasticity has positive relevancy with income level. The income elasticities of lowest and highest quintile of income groups respectively were 0.25 and 0.48. On the contrary price elasticity had negative relevancy with income level. Price elasticities of lowest and highest quintile of income groups respectively were -0.79 and -0.39. The trend of changes in income elasticity supported luxurious attribute of water and trend of changes in price elasticity suggested the potential on water saving by reasonable pricing policy to improve efficiency of water use. R.G. Taylor, John R. Mckean, and Rober A. Young (2004) [3] researched house water demand in Colorado of USA by establishment of water demand function which included dummy variables whether implemented the water resource protection planning, seasons and other variables such as annual highest temperature, income, marginal and average water price. The result showed average price coefficient was not significant by TSLS method using average price demand function. But when used demand function based on marginal price, price coffecient was -0.297 and significant. Income elasticities using demand functions based on average and marginal prices respectively were 0.382 and 2.84. This result suggested growth of income would lead to more use of water. Other researchers such as Danielson(1997)[4] analysed elasticity of Household Demand in Carolina of USA; Espey Espey and Shaw(1997)[5] adopted meta method to estimate elasticities.

3 Demand Estimation

3.1 Model of Demand Function

This study adopted AIDS(Almost Ideal Demand System)formed by Deanton and Muellbauer(1980)[6].Compared with Rotterdam and Translog demand models,it holds the advantages as follows[6]:gives an arbitrary first-order approximation to any demand system;it satisfies the axioms of choice exactly;it aggregates perfectly over consumers without invoking parallel linear Engel curves; it has a functional form which is consistent with known household-budget data; it is simple to estimate, largely avoiding the need for non-linear estimation; and it can be used to test the restrictions of homogeneity and symmetry through linear restrictions on fixed parameters.Although many of these desirable properties are possessed by one or other of the Rotterdam or Translog models, neither possesses all of them simultaneously.

AIDS model is :

$$w_{ih} = a + \beta_i \ln x_h + (\gamma_i - a\beta_i)\ln p_i - .5\beta_i\gamma_i(\ln p_i)^2 + \sum_k \varphi \ln z_{kh} + \varepsilon_i \tag{1}$$

$$PED = \frac{1}{w_{ih}}[\gamma_i - \beta_i(a + \gamma_i \ln p_i)] - 1 \tag{2}$$

$$IED = \frac{\beta_i}{w_{ih}} + 1 \tag{3}$$

w_{ih}—budget share for good i of household h

x_h—expenditure of household h

p_i—price of good i

z_h—characteristic variables of household h

PED—price elasticity of demand

IED—income elasticity of demand

$\alpha_{i,}\beta_{i,}\lambda_i$— parameters

3.2 Determinants of Water Demand

Besides the price and income in consumer demand theory, the following determinants should be considered.

(1) Weather

Weather variables were considered into analysis of household water demand in many research. Billings and Agthe (1980)[8], Nieswiadomy and Molina (1989)[9], and Billings (1987)[10] used soil evaporation minus rainfall as weather variable; Nauges and Thomas (2000)[11] choiced average annual rainfall and rainfall in annual summer(June-August), and Al-Quanibet and Johnston (1985)[12] used temperature, day-length regimes and wind speed variables. Generally assumed that summer evidently influences water demand and this paper choiced season as weather dummy variable.

(2) Family Size

Höglund (1999) [13] suggested scale effect of household water demand existed in water use. Arbués et al. (2000)[14] put forth an idea that there was an optimal family size for water demand and beyond this size, the scale effect would not exist. Gunatilake, Gopalakrishnan and Chandrasena(2001)[15] found the household water demand had scale effect in Sri Lanka; The result from Lyman (1992) [16] suggested variety of water use were derived from people of all ages. Children were assumed to use more water and retired people tend to do more gardening. Research in France from Nauges and Thomas (2000)[11] supported this idea. This paper assumed family size was an important element and put it into the demand function.

(3) Water Apparatus

Similar to research on electricity demand, water apparatus can present the difference between short-run and long-run reactions. The result from Nauges and Thomas (2000)[11] suggested compared with the communities without showers, communities with showers consumed more water. In consideration of availability of data and practical situation in Beijing, this paper used statistics of shower and washing machine from per hundred households survey to represent the characteristics of water apparatus of different income groups

(4) Frequency of Payment

Frequency of payment presented household recorded expenditures on water in a given year. For the household with higher frequency of payment, they were assumed to be more familiar with the structure of water price and the relationship between water consumption and water bill and were more economical on water use (Arbués et al. 2000)[14]. On the contrary, coefficient of frequency of payment from Stevens et al (1992)[17] was negative. This implied lower frequency of payment and lump sum payment gave some kind of shock effect on household. Kulshreshtha (1996)[18] did research on price elasticities under different frequencies of payment. This paper put frequency of payment in demand function to analyse its impact on water demand.

(5) SARS

Because of SARS happened in 2003, more people stayed at home. This may affect the water demand at that time. Period was considered from April to June in 2003 as dummy variable.

By analysis of determinants of water demand, this paper took the form of AIDS model as follows:

$$w_{ih} = a + \hat{\beta}_i \ln x_h + \left(\gamma_i - a\hat{\beta}_i\right)\ln p_i - .5\hat{\beta}_i\gamma_i\left(\ln p_i\right)^2 + \varphi_1 Summer + \varphi_2 SARS + \varphi_3 Freq + \varphi_4 \ln WashM + \varphi_5 \ln Shower + \varphi_6 \ln avper + \varepsilon_i \quad (4)$$

① w_{ih} -- water expenditure share

② p_i --real price of water

③ x_h --real monthly expenditure

④ $Summer$ --weather variable

⑤ $SARS$ ——SARS

⑥ $WashM$ --washing machine

⑦ $Shower$ --shower

⑧ $avper$ -- family size

⑨ $Freq$ -- frequency of payment

Price and income elasticities can be estimated by formular(2)and(3)

4 Empirical Study

4.1 Data

Data of this research included two categories:①One household level data were taken from the Chinese Urban Household Income and Expenditure Survey(HIES). The survey required respondents to keep a daily expenditure diary for a full 12 month period. These data contain monthly information from 3792 households in 9 districts of Beijing for the years from 2002 to 2006②In consideration of little variation in price, another category of data was used. It is collected by the local State Statistical Bureaux and aggregate statistics were compiled and published on an annual basis in the Province Statistical Review for the years from 1998 to 2006. In general, raw, household level, data was not available to the general public. One of the only ways in which the data was disaggregated in a publicly available form was by income quintiles. I.e. data was presented as average expenditures for each of these 5 income groups[5]. Both of the two categories were panel data.

4.2 Estimation Method and Results

The data limitations described above are not uncommon. On the one hand this paper had a long time series which provided variation in 'macro' variables, in this case the price of water, but very little variation in the 'micro' household level characteristics. On the other hand this paper had a cross section of households with variation in important micro characteristics, but with very little variation in the important macro

5

data. Initial estimations based solely on the aggregated data provided significant estimates for price elasticities, but not for income elasticities. The opposite was true for the household level data. In order to resolve this issue, this paper used a two step method originally from Tobin (1950) [19].

This paper followed Tobin's method which consisted of the following three steps[6]:

i. This paper estimated income elasticity(Panel IED) and price elasticity(Panel PED) from cross-sectional data from 2002 to 2006.

ii. This paper multiplied the estimated income elasticity by the time-series income variable and subtracted the product from the annual time series data for water quantity to form a new dependent variable.

iii. This new dependent-variable series was then regressed against the time series of the price from 1998 to 2006 to obtain an estimate of the price elasticity(Tobin PED) of demand.

Result showed in Figure.1:

Figure.1 Elasticities of Demand and Coefficients of Other Determinants

Income Group / Coefficient	1	2	3	4	5
Panel IED	0.1750**	0.0623**	0.0247**	0.0346**	-0.0489**
Panel PED	-0.8556	-0.7554	-0.6776	-0.8098	-0.7442
Tobin PED	-0.0718	-0.0172	0.0425	-0.3656	-0.0407

6 To make full use of data and consider the cross-sectionally correlation, the demand function created a set of interaction terms for income group and explanatory variables. A Hausman test showed that a fixed effects model was appropriate for the data. The important assumption of Tobin's method is that the income elasticities for 2002-2006 can be applied to all the years of the chosen time series.

lnShower	0.0088**
lnWashM	-0.0109**
lnAvper	0.009
frequency	0.0104**
Summer	0.0005**

Note: “**” indicates a parameter significant at the 1% level

Figure.2 Annual Average Water Consumption Per Household From 1998 to 2006 (ton/a) (three members per household)

Income Group	1	2	3	4	5
Annual Average Water Consumption	66.9	78.3	81.6	89.4	101.7

Figure.3 Water Consumption Per Household in 2006 (ton/a) (three members per household)

Income Group	1	2	3	4	5	6	7
Water Consumption	78.96	95.52	109.2	108.96	110.28	121.32	122.52

Given the longer time span analysed, these parameter estimates were probably best interpreted as long-term price and income elasticities. As one would expect, the estimates of the IED were between zero and one and hence water can be classified as a necessity in economic terms. The IEDs range from 0.175 for the 0-20% quintile to 0.025 for the 40-60% quintile. It should also be recognised that the income elasticity was higher for the low income households:they spent a higher proportion of additional income upon water than did higher income households.Oddly,however,the IED for the highest quintile of income was negative,implying that water consumption had reached saturation point for basic demand and water was in fact an inferior good for highest income group.For further analysis,Annual average water consumption per household from data of second category and water consumption per household from panel date in 2006 were respectively calculated by divided into seven income quintile groups.Result showed①Groups with higher income level consume more.②Water consumption in Beijing is mainly indoor use, even rich people have few private lawns for irrigation, and there were few private swimming pools[7] and the ways of indoor use were limited and increment of consumption were small fraction. For the highest quintile of income, incease of income could not remarkably contribute to water consumption. Therefore, water consumption increases slowly with income. ③Although income elasticity of the highest quintile of income was negative, there were limited water consumption behaviors of substitute and it consumed most. ④Negative income elasticity of the highest quintile of income implied, for this group, the luxurious part of consumption became inferior good. Along with the increase of income, the consumption behaviors of substitute would work and the part of luxury would decrease. See Figure. 2 and 3.

Result from data of two categories supported the coefficient of price was not significant and implied changes in price did not affect household water demand. Water price had not reached the threshold of response of household to price and water price policy of Beijing had not yet give full play to the role of water demand management.

Both coefficients of shower and washing machine were in accord with the facts. Household with shower consumed more and function of water saving of washing machine reduced water consumption; Family size did not affect water use and this implied there was no scale effect in household water consumption in Beijing; Coefficient of frequency of payment was positive and higher frequency of payment implied less water expenditure share. This result was contrary to that of Arbués et al (2000); Weather had noticeable effect on water and summer caused more water use; Finally variable sars was dropped out because of colinearity.

5 Conclusion

This paper comparatively analysed behaviours of water use of different

[7] Personal comment Xiaoying Liu.

income groups based on AIDS model by estimation of income,price elasticities and other coefficients of household demand.Results showed below:

i:All income elasticities from the first four income groups were positive and less than 1.This result implied water was necessity.For household with lower income ,increments of income relatively would be spent more on water consumption to improve satisfaction of basic water needs.

ii:Negative income elasticity of the highest quintile of income implied,for this group,the luxurious part of consumption became inferior good.With increase of income,this part would reduce.

iii：The two methods did not support price had significant effect on water use.This result implied water price policy of Beijing could not play an important role in water demand management.

iv:All other determinants had effects on water use except for family size.Positive coefficient of shower showed family with shower consumed more water and negative coefficient of washing machine presented family with washing machine consumed relatively more water.Higher frequency of payment implied higher water expenditure share.Summer could increase water consumption and sars was dropped out because of colinearity.

References

[1]Henry S.Foster,Jr and Bruce R.Beattie.1979.Urban Residential Demand for Water in the United States,Land Economics,55(1):44-58

[2]Koundouri and Pashardes. Household Water Demand and the This paperlfare Implications for Water Pricing in Cyprus. Environment and Development Economics,Discussion Paper,2001

[3]R.G.Taylor,John R.Mckean,and Rober A.Young.Alternate Price Specifications for Estimating Residential Water Demand with Fixed Fees.Land Economics,2004,80(3):463-475

[4]Danielson,Leon E.1977.Estimation of Residential Water Demand.Economics Research Report,No.39

[5]Espey,M.,J.Espey,and W.D.Shaw.1997.Price Elasticity of Residential Demand for Water:A Meta-Analysis.Water Resources Research,33(6):1369-74

[6]Deaton,Angus,and Muellbauer,John.An Almost Ideal Demand System.American Economic Review:1980,70:312-326

[7]Banks, James, Richard Blundell,Arthur Lewbel.Quadratic Engel Curves and Consumer Demand.Review of Economics & Statistics.1997,79(4):527-539.

[8] Billings, R. B. and Agthe, D. E., 1980. Price elasticities for water: a case of increasing block rates. Land Economics,56(1):73-84

[9]Nieswiadomy, M.L., Molina, D.J.,1991.A note on price perception in water demand models. Land Economics 67(3),352-359.

[10]Billings and Agthe.Equity,Price Elasticity and Household Income Under Increasing Block Rates for Water.American Journal of Economics and Sociology, 1987,46(3):273-286.

[11]Nauges and Thomas.Privately Operated Water Utility,Municipal Price Negotiation,and Estimation of Residential Water Demand:The Case of France.Land Economics,2000,76(1):68-85.

[12]Al-Quanibet, M.H., Johnston, R.S., 1985. Municipal demand for water in Kuwait: methodological issues and empirical results. Water Resources Research 2(4):433-438.

[13]Höglund, L,.Household demand for water in SThis paperden with implications of a potential tax on water use.Water Resources Research 35 (12):3853-3863.

[14]Arbués, F., Barberán, R.,Villanúa, I.,2000.Water price impacts on residentialwater demand in the city of Zaragoza.A dynamic panel data approach. Paper presented at the 40th European Congress of the European Regional.

[15]Herath M.Gunatilake,Chennat Gopalakrishnan,Inoka Chandrasena.The Economics of Household Demand for Water:The Case of Kandy Municipality,Sri Lanka. Water Resources Development 2001,17(3):277－288
[16]Lyman, R.A.,Peak and off-peak residential water demand. Water Resources Research 28(9):2159－2167.
[17]Stevens, T.H., Miller, J., Willis, C., Effect of price structure on residential water demand. Water Resources Bulletin 28(4):681－685.
[18]Kulshreshtha,S.N.Residential Water Demand in Saskatchewan Communities: Role Played by Block Pricing System in Water Conservation.Canadian Water Resources Journal21(2):139－155.
[19]James Tobin.A Statistical Demand Function For Food In The U.S.A.Jounal of The Royal Statistical Society.113(2):113-149.
[20]Income Related Incidence of the This paperlfare Impacts of Water Pricing，Report For The China Council For International Cooperation On Environment And Development,2005.
[21]Deng liangchun,Zhang shiqiu.The function of price policy in water demand management.Peking Universtiy,Beijing,2006.
[22]Yuepeng,Zhangshiqiu. Research Of Efficiency And Equity In Urban Water And Sanitation Pricing Policy—A Case Study In Beijing.Peking Universtiy,Beijing,2008.

Water Quality and Environmental Treatment Facilities

Geum Soo Kim, Young Jae Chang, David S. Kelleher[1]

August 2010

<<Abstract>>
It has been argued that investment in basic treatment facilities could have both a direct, positive effect and an indirect, negative effect on water quality. Using a two-stage least-squares method we have shown that the net effect of investment in basic treatment facilities on water quality in Korea is positive and statistically significant. Nevertheless, the findings also reveal a statistically significant, negative relationship between the volume of wastewater and water quality. These findings can be interpreted to suggest that facilities construction has not kept pace with treatment demands. Alternatively, these findings may also reflect firm behavior regarding wastewater discharge in the face of regulatory enforcement. We thus propose and test a novel model that is capable of simultaneously considering interactive behavior on the part of both firms and regulators and the resulting water quality this interaction gives rise to. The model and results draw attention to the importance of optimally balancing efforts to build wastewater treatment facilities with efforts to set and enforce regulatory standards.

Key Words : Basic Treatment Facilities, Water Quality, Enforcement, Regulation,

[1] Kim: Corresponding Author, Professor, Department of Economics, Hoseo University, Cheonan City, Rep. of Korea. (E-mail : gsgim@hoseo.edu, Phone : +82-41-560-8337);
Chang: Professor, College of Business Administration and Institute for Industrial Management, Inje University, Kimhae City, Rep. of Korea;
Kelleher: Professor, Department of Public Administration, Hoseo University, Cheonan City, Rep. of Korea.

1. Introduction

Water quality in natural waterways is a public good. Once one party in a society exerts an effort to improve the water quality in lakes, rivers, etc., other parties will enjoy the benefits with no additional cost. Due to this non-rival and non-excludable attribute of public goods, they tend to be under-provided from the society's point of view. This is one of the rationales for government intervening in the market. To attain a socially optimal level of water quality, a government may impose a regulation on potential polluters that guides their behavior in accordance with the socially optimum level of pollution. At the same time, the government may also attempt to ensure the desired water quality by directly treating wastewater before it is discharged into the river. As in many countries, the Korean government makes both efforts to ensure water quality. In the 1980s, the Korean government introduced new water quality standards and increased enforcement efforts. In the 1990s, the government significantly expanded its so-called basic treatment facilities, which includes facilities for treating municipal wastewater, industrial wastewater and livestock wastewater. As of 2009, there were approximately 600 treatment facilities in operation throughout the country.

Thus, water quality is determined by efforts to regulate the amount and composition of wastewater emitted by households and firms as well as through government efforts to directly treat these emissions. However, most analyses focus on only one part of this situation at a time. (Garvie and Keeler, 1994; Neilson and Kim, 2001; Kwak and Kim, 1995; Kang, 2003). Kim and Chang (2007) is an exception. They have provided a theoretical model for a budget-constrained environmental regulatory agency, whose budget is allocated towards operation of basic treatment facilities as well as for monitoring and punishment. In fact, local autonomous governments in Korea are responsible for monitoring and imposing fines on the violators and they are also charged with the operation of most basic treatment facilities, while a superior agency like (in this case, the central government) is mostly responsible for constructing the treatment facilities and providing the overall budget to autonomous governments. In this paper we examine whether increased investment in basic treatment facilities has improved water quality in Korea, with the analysis conducted within the framework provided by Kim and Chang (2007).

Kwak and Kim (1995) and Kang (2003) have already reviewed the Korean experience and argued that investment in basic treatment facilities has been quite effective in improving water quality. However, their analysis is limited in the sense that they have not used the real water quality data for the dependent variable in their regression analysis, but rather used estimated water quality difference data; also, the treatment facility is assumed to be the only factor determining the water quality. They begin by estimating a counterfactual trend in water quality that they presume would have obtained in the absence of treatment facilities. Then they compare this counterfactual trend with the real water quality trend, and assess whether investments in basic treatment facilities adequately explain the resulting differences in water quality. They simply assume that without the basic treatment facilities the water quality would have deteriorated in accordance with the preexisting trend. To some extent, they have assumed away the problem by positing that these investments are predominantly responsible for (presumed) changes in water quality levels. In contrast, we will run a regression on real water quality data wherein we allow both treatment facilities and regulation to affect the water quality.

In the next section we are going to reproduce Kim and Chang's (2007) model briefly, which argues that investment in basic treatment facilities has both a direct, positive effect on water quality and an indirect, negative effect on water quality. The reason why the investment in basic treatment facilities could have a negative effect is that the investment in treatment facilities could affect a budget-constrained regulatory agency's choice in a way that would perversely encourage the regulated firms' emissions, giving a negative result in terms of water quality. We have tested this hypothesis with the Korean experience. Since investment in treatment facilities is one of the important explanatory variables for water quality while at the same time being endogenously determined within the regulatory framework, we have run a two-stage least squares regression. We find that investment in basic treatment facilities has been quite effective in improving water quality and its indirect, negative effect is almost negligible. In the last section, we provide a summary of our main arguments and draw attention to limitations to be addressed in future work.

2. Theory

A strategic interaction between a regulatory agency and n homogeneous regulated firms is considered. With a given budget and a given level of treatment facilities the agency first sets enforcement parameters, and then the firms respond to the agency's choice by choosing an amount of emissions. In other words, the agency behaves like a Stackelberg leader and the firms act like Stackelberg followers. So the analysis begins with the regulated firms. We are going to focus on the choice of a representative firm. The firm is assumed to minimize its abatement cost C plus expected fine pf by choosing its emission level x as indicated.

$$Min_x \ C(x) + pf(x - s, E)$$

Those two factors C and pf all depend on the firm's emission level x, and the fine f depends also on an environmental standard s and the strength of the agency's enforcement will E. The fine would increase as either the emission increases relative to an environmental standard, or the agency takes a stronger posture for enforcement. The probability of violators getting detected is denoted by p and the fine f is exogenously determined; thus, the monitoring probability p coupled with the fine f constitute an expected fine pf. The first order condition for this optimization problem is $-C_x = pf_x$, which means that as a rational firm increases a marginal unit of emission, the saved abatement cost should equal the increase in expected fine. Also, using the second order condition we can easily show that the optimal choice regarding emission, say x^* would decrease as the agency increases either p or E.

Knowing this firm's response, the regulatory agency is assumed to minimize so-called net non-compliance with a budget constraint as in the following:

$$\begin{aligned} &Min_{p,E}\ n(x^*(p,E)-s)-g \\ &s.t.\ M(p,E)+A(g)\le B \end{aligned}$$

Here the non-compliance level of a firm is $x^* - s$ and so the total level of non-compliance is $n(x^* - s)$. Now the government treats the waste water directly, as reflected by g. The actual amount of g depends on the capacity of government constructed treatment facilities and we just assume for simplicity that g equals that capacity. Now, the net non-compliance is $n(x^* - s) - g$. $M(p,E)$ represents the agency's expenditure for monitoring and costs such as being involved in a lawsuit with a violator. $A(g)$ stands for the operational cost for treatment facilities. The total expenditure cannot exceed the agency's total budget, which is given by a superior agency like the central government. Notice that s, g and B are all given to the agency by a superior agency. Assuming an interior solution, the first-order conditions for this optimization problem are the following:

$$
\begin{aligned}
& n\frac{\partial x^*}{\partial p} - \lambda M_p = 0 \\
& n\frac{\partial x^*}{\partial E} - \lambda M_E = 0 \\
& \lambda[B - M(p,E) - A(g)] = 0 \\
& B - M(p,E) - A(g) \geq 0,\ \lambda \geq 0
\end{aligned}
$$

Here λ denotes the Lagrange multiplier. The first two equations are exactly the same as the conditions for the case where the agency's objective is just non-compliance rather than net non-compliance. This is because the g variable does not depend on p or E, but is just given by a superior agency. From these two equations we can derive the following equation:

$$\frac{(\partial x^* / \partial p)}{(\partial x^* / \partial E)} = \frac{M_p}{M_E}$$

The left hand side represents the slope of an iso-non-compliance curve at the optimum, while the right hand side represents the slope of the agency's budget line at the optimum. This is analogous to a rational consumer's optimization problem. Like a rational consumer, the agency tries to equalize the marginal contribution towards non-compliance of both monitoring expenditures and expenditures associated with litigation. This raises an interesting question, namely, does the variable g make any difference to the agency's choice? The answer is not simply "no" because, even though with g the way the agency makes a choice remains the same, g affects the position where the choice is made. In other words, the variable g does not enter into the above equation, but it enters into the agency's objective function and its budget constraint. The variable g does reduce the non-compliance level directly but with a reduced enforcement budget. The net effect is not clear. That is, introducing g may or may not reduce the non-compliance. In other words, introducing g may or may not improve the water quality.

3. Estimation Equation and Data

Since the treatment facilities may or may not improve the water quality from a theoretical point of view, we are going to review the Korean experience and test if the treatment facilities have improved water quality since 1991. In order to test the hypothesis we specify the following simultaneous equation system. The reason why we have a simultaneous system is that the water quality is not only determined by treatment facilities, but also by regulatory activities, and the treatment facilities are endogenously determined by regulatory variables.

$$WQ_i = \beta_{10} + \beta_{11} BEF_i + \beta_{12} WW_i + \beta_{13} PRE_i + \varepsilon_{1i}$$
$$BEF_i = \beta_{20} + \beta_{21} ENF\_PUNS_i + \varepsilon_{2i}$$

We use data regarding the four main rivers in Korea covering 1991 through 2006, but the data is not river-specific, but yearly aggregate data. These data are available at the Korea Ministry of Environment web page (www.me.go.kr) which provides access to the Environmental Statistics Yearbooks, the only data source we have relied upon. The dependent variable is water quality (denoted by WQ) and there are many indicators for water quality, among which we are going to use BOD (biological oxygen demand) for the sake of convenience. The explanatory variables are BEF, ENF_PUNS, WW, and PRE. BEF represents Basic Environmental Treatment Facilities which includes municipal sewage, industrial wastewater, and livestock wastewater treatment facilities. BEF is a stock variable (unlike investment in treatment facilities, which is a flow variable); BEF is an accumulated investment measured in terms of tons per day of wastewater treatment capacity. The unit of measurement is 1,000s of ton per day. ENF_PUNS is an enforcement variable. It is the product of ENF and PUNS. ENF represents the average number of inspections per year per wastewater-discharging firm; PUNS represents the strength of punishment imposed on violating firms. There are six different types of punishment: Warning, Improvement Order, Temporary Operation Stoppage, Operation Expiration, Plant Closure, and Prosecution. We have given an arbitrary point value to each of these different types of punishment types with a higher value assigned to a harsher punishment type and then we have summed them up into a measure, PUNS. So ENF_PUNS reflects both monitoring frequency and punishment strength. ENF_PUNS does not have a special unit, but is simply a number.

WW represents wastewater, the unit of which is 1,000 square meters per day. There are different types of wastewater, i.e., municipal sewage, industrial wastewater and livestock wastewater, but we use only the data for industrial wastewater due to gaps in availability. Moreover, the data for industrial waste water in 1999 and 2000 are absent and so we have interpolated estimates based on the yearly trend. PRE stands for the national average of precipitation. Summary statistics for the data we use in the empirical analysis are provided in the following table.

<Table 1. Summary Statistics>

Variable	Obs.	Mean	Stand. Dev.	Min.	Max.
WQ	16	3.45125	0.4625131	2.58	4.3
BEF	16	15856.94	6469.331	5525	24157
ENF_PUNS	16	7520.75	928.8885	5656	8926
WW	16	31178.89	26346.41	8036.842	101625.1
PRE	16	19413.38	24966.53	8893	112564

4. Empirical Results

BEF is not independent of WQ because it is influenced by ENF_PUNS and WW. So we have applied a two-stage least-squares method for estimating the effect of treatment facilities on water quality. The instrument variables for estimating BEF are ENF_PUNS, WW and PRE. After estimating BEF we have regressed WQ on the estimated BEF, WW and PRE, getting the result in <Table 2>. The estimation results confirm the previous authors' argument that building treatment facilities has been quite effective in improving the water quality. The coefficient for BEF implies that other things being equal, an increase in treatment capacity by 1,000 tons per day would lead to the water quality being improved by 0.0544 BOD decrease.

<Table 2. 2SLS Regression Result>

Variable	Coefficient	Stand. Error	t-statistic	P-value
C	2.223159	0.8259682	2.69	0.020
BEF	-0.0000544	0.0000191	-2.86	0.014
WW	0.0002819	0.0001251	2.25	0.044
PRE	-1.49E-06	4.18E-06	-0.36	0.728

It is also shown that the increase in wastewater has deteriorated the water quality. The corresponding coefficient is statistically significant. This result implies that the wastewater has been increasing in excess of total treatment capacities or actually utilized capacities. Otherwise, the variation in wastewater would not have affected the water quality in a statistically significant way. The size of the coefficient is small, though. The increase in waste water by 1,000 tons per day, other things being equal, would lead to only a 0.0001251 BOD increase. WW measures just the volume of wastewater. But the pollutant concentration of wastewater is also critical in determining the extent to which treatment is effective and results in adequate water quality, and the firms' emissions and the pollution concentration in wastewater are affected by regulatory variables. So WW, being a measure of quantity, does not capture potentially important quality considerations. This has important policy implications insofar as the building of treatment facilities, by itself, will not guarantee a given level of water quality in the absence of sufficient regulation and enforcement. Lastly, the sign of the estimated coefficient for PRE conforms to our commonsense reasoning, but it is not statistically significant.

One important question that we have asked is the extent to which the positive effect on water quality associated with increased investments in basic treatment facilities is offset by the indirect, negative effect of reduced potential enforcement activities. The above result tells us that the net effect was positive on water quality, i.e., we can say that building treatment facilities has contributed to improving the water quality even with consideration of the negative effect through reduced enforcement efforts. Just for a reference we provide the OLS regression results. As you can see in <Table 3>, the negative effect can be thought to be small.

<Table 3. OLS Regression Result>

Variable	Coefficient	Stand. Error	t-statistic	P-value
C	2.233893	0.818156	2.73	0.018
BEF	-0.0000539	1.89E-05	-2.85	0.015
WW	0.0000280	0.000124	2.26	0.043
PRE	-1.57E-06	4.17E-06	-0.37	0.713

5. Concluding Remarks

The main question of this paper is whether building treatment facilities has improved water quality. Previous authors have argued that the facilities have been quite effective in improving the water quality. However, their analysis is limited in the sense that they have not used real water quality data for the dependent variable in their regression analyses, but rather estimated data, and also the treatment facility is assumed to be the only factor determining the water quality. This paper is different in that we have run a regression on real water quality data and we have allowed both treatment facilities and regulation to affect the water quality.

With a structural equation model we have run a 2SLS regression and shown that building treatment facilities has contributed to improving the water quality even with consideration of the negative effect through reduced enforcement effort. It is also shown that an increase in wastewater has deteriorated water quality. This result implies that WW might have deteriorated the water quality through the induced firms' emissions. An important policy implication is that building treatment facilities alone does not guarantee water quality, but depends in addition on proper regulation and enforcement. One critical limitation with this paper is that the number of observations in the empirical analysis is limited. With an expanded data set including river-specific data for all the variables we could conduct a more meaningful analysis. This is left for future research.

References

Garvie, D. and Keeler (1994), "Incomplete Enforcement with Endogenous Regulatory Choice," *Journal of Public Economics*, Vol. 55, pp. 141-162.

Kang, M. (2003), "A Research on Reforming Korean Environmental Budget," RE-08, Korea Environment Institute. (in Korean)

Kim, G. and Y. Chang (2007), "Investment in Basic Treatment Facilities and Environmental Regulation," *Journal of Regulation Studies*, Vol. 16(2), pp.175-193. (in Korean)

Korea Ministry of Environment, *Environmental Statistics Yearbooks*, all relevant issues. (in Korean)

Kwak, T. and H. Kim (1995), "A Study on Improving Korean Environmental Budget Policy," WO-04, Korea Environmental Technology Research Institute. (in Korean)

Neilson, W. and G. Kim (2001), "A Standard-Setting Agency and Environmental Enforcement," *Southern Economic Journal*, Vol. 67(3), pp.757-763.

An Analysis on Statistical Indicators and Methodology of Environmental Investments in China

WANG Jinnan　LU Yuantang

（Chinese Academy for Environmental Planning, Beijing, 100012）

Abstract: The environmental investment is an important guarantee for materializing the basic national policy of environmental protection and implementing the sustainable development strategy. Though Chinese government has attached great importance to environmental protection with continued efforts in increasing environmental investment, there are still some fundamental issues to be addressed with regard to environmental investment. Based on the concept identification of environmental investment, input, and expenditure, this paper has made comparative analysis on the concept of environmental investment in China and in other countries and systematically analyzed the statistical scope, indicators, and method of environmental investment currently exercised in China. Analysis results show that China's statistical system for environmental protection investment is far from well-established, lacking standardized data management of environmental protection investment; without clear definition of environmental protection investment and unified statistical scope; weak scientific basis of statistical methodology with duplicated calculation or time inconsistency. To improve the statistical system of China's environmental protection investment and get a real picture of environmental protection investment，the paper suggested recommendations in aspects of adjusting the statistical scope of environmental investment, developing statistical methodology with strong scientific basis, and improving the statistical system of environmental investment.

Key words: environmental investment, environmental statistics, China

The environmental investment is an important guarantee for materializing the basic national policy of environmental protection and implementing the sustainable development strategy. Knowing its important role in improving environmental quality China has been making efforts in increasing environmental investment since 1980s. In 2008, the statistical nominal environmental investment was 449 billion RMB yuan accounting for 1.49% of GDP in that year. However, there are still some fundamental issues to be addressed with respect to the environmental protection investment. The connotation of environmental investment is not clear, being difficult to compare with those of foreign countries. The statistics on environmental investment is inconsistent with the real situation due to the flaw of the statistical system and lacking standardized statistical scope and methodology, that adversely affects the environmental planning and environmental policy making.

1 Comparative analysis on the concept of environmental investment

1.1Environmental investment: cost-based or investment-based?

(1) Cost-based environmental investment

This concept is typically adopted by the U.S. and Japan who started environmental control and treatment comparatively early, in that the environmental investment means the costs of environmental protection, i.e. the total cost paid by the whole society on pollution control and environmental quality improvement in order to maintain certain level of environmental quality[1]. It is typical in the U.S. that all financial input in environmental protection has been considered as the cost of environmental protection. There is similar understanding in China that "all cost spent on restoration/ proliferation, protection, and treatment of environmental resources should be considered as environmental investment[2]", or environmental investment is the "total capital paid for protecting resources and controlling environmental pollution[3]".

(2) Investment-based environmental investment

Another explanation on the environmental investment is "investment-based environmental investment" which suggests that environmental investment is an important component of fixed assets investment in economic and social development, being a policy investment in terms of the investment bodies. It is considered that environmental investment as a comparatively independent and special investment in economic and social development is of not only the general attributes but also its own special attributes. That is, 1) enterprises are the main bodies of environmental investment; 2) The environmental investment bodies are not necessarily the beneficiaries;3) The benefit of investment is mainly shown in environmental improvement; 4) it is hard to value the benefit of environmental investment in monetary term.

1.2 Three concepts related to environmental protection investment

(1) Environmental investment

There is no common definition of environmental investment in China. There are diverse understanding of environmental investment, no clearly defined statistical scope and method for environmental investment[4]. In general, the environmental investment in China mainly includes investments in industrial and regional pollution control, construction of environmental infrastructures (e.g. urban waste water treatment plant) and the capacity building of environmental protection departments, etc. usually not including the investment in ecological conservation. Therefore, the environmental investment in China is usually mentioned as environmental pollution control investment, meaning the fixed assets investment in the treatment of industrial pollution source and construction of urban environmental infrastructures, including the funds spent on environmental engineering projects of industrial pollution control for both existing and new sources, "santongshi*" environmental investment in construction projects, and construction of urban environmental infrastructures[5].

(2) Environmental input

The environmental input means the funds from social accumulation fund and various compensation and production/business funds, and spent by relevant investment bodies in the society on preventing and controlling pollution and protecting and improving ecological environment in the process of national economic and social development. In accordance with the common practice both at home and abroad, the environmental input is usually defined in terms of objectives or effectiveness. In objective-based definition, the environmental input includes input in environmental pollution control, input in the conservation of ecological environment, and input in environmental management and science and technology. Also, the environmental input could be classified into fixed assets investment of environmental protection, maintenance and operation costs of environmental engineering or facilities, and funds for environmental management and R&D.

(3) Environmental expenditure

Environmental expenditure means the costs incurred in conducting environmental protection activities, including the depreciation of fixed assets which were utilized in the environmental protection activities, costs of raw materials that were consumed, costs of fuels and power, employee's salary and additional income, and pollution discharge fee, etc.

* The environmental facility has to be designed, constructed, and put into operation at the same time when the main body of a construction project that will generate pollutants is designed, constructed and put into operation.

1.3 Concept of environmental expenditure in developed countries

The concept of environmental expenditure is commonly used in developed countries. The concept of environmental protection expenditure in EU is quite different from the concept of environmental protection investment in China in terms of their connotation, scope, and statistical method.

The concept of environmental expenditure has been used in EU in stead of an independent concept of environmental protection investment. In the European System for the Collection of Economic Information on the Environment (SERIEE), the environmental expenditure is the capital expenditure plus recurrent expenditure spent on environmental protection. There are nine expenditure categories of environmental protection activity in terms of the content of environmental protection activities in the internationally agreed classification of environmental protection activities (CEPA2000). The environmental protection activities can also be divided into independent environmental protection activities and environment friendly activities. The environmental protection activities here are different from business activities of enterprises. The environmental protection expenditure mainly means the expenditure on independent environmental protection activities, not including the expenditure incurred on environment friendly activities (e.g. natural gas project).

The Statistical Office of the European Union (Eurostat) defines the environmental protection expenditure as the sum of recurrent expenditure and capital expenditure. The recurrent expenditure includes operational costs of environmental facilities, expenditures on environmental management and R&D, expenditures on purchasing non-fixed assets, expenditure on environmental services, and special taxes, etc. The capital expenditure includes costs on the end-of-pipe pollution control and the comprehensive production process, in which the cost for end-of-pipe pollution control is mainly spent on waste water, solid waste, and air pollution treatment. The Statistical Office of the European Commission (SOEC) defines the environmental protection expenditure as expenditures on reducing and preventing air and water pollutants, protecting and cleaning soil and ground water, reducing, treating, and disposing solid wastes, including operational cost (OPEX) and capital expenditure (CAPEX). In Germany, environmental expenditure also includes the recurrent expenditure and capital expenditure.

In the United States, all financial input in environmental protection is considered as environmental protection cost which can be divided into damage cost, protection cost, and clean-up cost. In the United Kingdom, the environmental protection cost includes operating expenditure and capital expenditure. In Finland, the public environmental expenditure includes the operational cost and capital expenditure of environmental protection facilities/equipment, and financial input in compensation fund and others.

1.4 Comparison of concepts on environmental investment in China and developed counties

The concept of environmental protection expenditure commonly used in North American countries, European countries, and Japan includes the capital expenditure and recurrent expenditure. Its covering scope is broader than the concept of environmental investment used in China.

(1) In EU, the operational cost of environmental facilities of enterprises is included in the environmental protection expenditure. The recurrent expenditure on pollution control includes the expenditures related to the operation of pollution control facilities and monitoring, such as operation cost of waste water treatment plants, cost of solid waste collection and disposal, pollution monitoring, etc.

(2) In Eurostat’s statistical report on environmental expenditure, with regard to afforestation/greening, only the expenditures on planting trees, green zones, green shelters surrounding industrial parks and factories were listed as environmental protection expenditure. In UK, it is clearly provided that the urban environmental expenditure should be excluded from the statistical scope for environmental protection expenditure. In China, the expenditure on urban greening has been listed as environmental investment.

(3) In EU, the investment in projects that are of environmental benefit is not included in the environmental protection expenditure. According to EU's criteria, the environmental protection investment includes investment in pollution control and part of urban public infrastructure, not including the expenditure on environment friendly activities. In contrast, the investment in the central heating, natural gas, etc has been considered as environmental protection investment in China - this entails further discussion.

(4) In EU, the investment in clean production has been listed as the environmental protection expenditure. Eurostat's capital expenditure on pollution control includes the cost of comprehensive production process, which was defined as the additional cost of employing novel production process to realize cleaner production. That is, the additional investment in clean production for the purpose of reducing pollution should be listed as environmental protection expenditure.

Table 1 Comparison between environmental investment in China and environmental expenditure in EU

type	China	EU
Operational cost of pollution control facilities and monitoring cost in enterprises	Not included in environmental investment	Listed as environmental protection expenditure
Investment in urban greening and sanitation	Listed as environmental investment	Only the expenditures on planting trees, green zones, green shelters surrounding industrial parks and factories are listed as environmental protection expenditure
Investment in projects having environmental benefit	Investment in projects of natural gas and central heating is listed as environmental investment	Not included in environmental protection expenditure
Investment by enterprises in clean production	Not clear	Listed as environmental protection expenditure
Cost of capacity building on environmental management and environmental management services	Not clear	Listed as environmental protection expenditure

2 Statistics of China's environmental protection investment and its problems

2.1 Statistical system of environmental protection investment

It is requested in State Council's decree on some issues related to environmental protection (1996) that " input to environmental protection be increased with the percentage of environmental pollution control input in GNP at the same period being increased, and a corresponding check and supervision system be established." To unify the scope of environmental protection input and to facilitate the calculation of environmental protection input in national economic and social development decision-making, a 《Notification on the Establishment of the Survey System of Environmental Protection Investment》 was issued by the State Administration of Environmental Protection (SEPA) in 1999, which as a key regulation on statistical system of China's environmental protection investment has clearly defined the classification and statistical scope of environmental protection input, provided for the statistical survey method of environmental pollution control investment and environmental management capacity building investment.

2.2 Statistical scope of environmental protection investment

According to the requirements in the 《Notification on the Establishment of the Survey System of Environmental Protection Investment》, the statistical scope of environmental pollution control investment (environmental protection investment) should cover three aspects: (1) investment in the construction of urban environmental infrastructure including urban waste water drainage, central heating, fuel gas, landscape greening, urban sanitation, etc., which can be reflected in the annual report on urban construction; (2) Investment in industrial pollution control. This mainly indicates the investment of existing polluting enterprises in pollution control by combining technical innovation and clean production. Data are mainly available from the annual report on environmental statistics; (3) “Santongshi” environmental protection investment of construction projects. It means the investment in the pollution control facility which has to be designed, constructed, and put into operation at the same time when the main production facility of a construction project that will generate pollutants is designed, constructed and put into operation. This kind of investment is an important component of environmental protection investments. Data can be obtained from the annual report on environmental statistics.

2.3 Statistical method of environmental protection investment

The statistical figures of environmental protection investment in urban infrastructure are derived from the “Comprehensive Form of the Fixed Assets Investment in the Construction of Urban Public Utility”. The statistical figure of investment in the treatment of industrial pollution sources is a component part of the comprehensive reporting system on environmental statistics of the environmental protection department. The enterprises whose industrial pollution control projects are still in construction will fill out the “Form on the Construction of Pollution Control Projects in Industrial Enterprises”. Then the environmental protection department will collect and compile those forms to generate a form on the construction status of industrial pollution control projects in all regions. The statistics of “Santongshi” environmental protection investment of construction projects are the component part of the reporting system of environmental statistics of environmental protection departments. A form on the implementation status of environmental impact assessment of construction projects in all regions will be generated by compiling the reporting forms from the lower level to the upper level. This part of environmental protection investment will be included in the “Santongshi” environmental protection investment of construction project of the same year when the project has completed and passed the final check and acceptance.

2.4 Major problems in environmental protection investment

First, there is no clear definition of environmental protection investment resulting in inconsistency in statistical scope. The statistical scope of environmental protection investment varies greatly from region to region because the boundary condition of statistical scope has not been well established. In this regard there is strong haphazard, usually subject to the understanding of individual statistical personnel on the question. The main problems are followings: (1) Whether the operation cost should be considered as the environmental protection investment; (2) Whether the input in ecological conservation and construction should be covered by environmental protection investment; (3) Whether the cost of capacity building of environmental management and cost of environmental management should be included in environmental protection investment; (4) Whether the investment in projects that can produce environmental protection benefit should be considered as environmental protection investment; (5) Whether the investment in clean production and the production of environment friendly products should be put within the scope of environmental protection investment. In the actual exercise of environmental investment statistics there is a trend of extending the scope of environmental protection investment and enlarging the absolute size of environmental protection investment either intentionally or unintentionally, resulting in a statistical figure of environmental protection investment being on the higher side and, in contrast, without harnessing the environmental pollution and getting tangible environmental quality improvement[6].

Second, the statistical method of environmental protection investment lacks strong scientific basis with lots of duplication and overlap in doing statistics. At present, the environmental protection investment consists of investment in the construction of urban environmental infrastructure, “Santongshi” environmental protection investment of construction projects, and investment in the treatment of industrial pollution sources, in which there is overlap in statistical scope resulting duplication of statistics. This mainly occurs as: (1) Duplication between “Santongshi” environmental protection investment and investment in the treatment of industrial pollution sources. The statistical figures of “Santongshi” environmental protection investment are based on the data in the project check and acceptance report that cover both “Santongshi” environmental protection investment of the newly constructed project and the environmental protection investment in pollution control of existing industrial pollution sources. (2) Duplication between “Santongshi” environmental protection investment and the investment in the construction of urban environmental infrastructures. The investment in urban waste water treatment plant and solid waste disposal facility counted in the investment in the construction of urban environmental infrastructures has also been considered in “Santongshi” environmental protection investment, resulting in the duplication in statistics. (3) Time inconsistency of the statistics of “Santongshi” environmental protection investment of construction projects with those of investment in the treatment of industrial pollution sources and in urban environmental infrastructures. Currently, the statistics of “Santongshi” environmental protection investment of construction projects are derived from the project check and acceptance report. If the construction period of the project is longer than one year, the “Santongshi” environmental protection investment will be the accumulated investment rather than the annual investment and only be counted for the year when the project is completed and accepted.

Third, the statistical system of environmental protection investment needs to be improved, especially in data management. (1) Dispersed management of data on environmental protection investment with low level of coherency. The investment in the construction of urban environmental infrastructure, “Santongshi” environmental protection investment of construction projects, and the investment in the treatment of industrial pollution sources are managed by different departments thus resulting in poor coherency of statistical indicators among these three component parts of environmental protection investment. (2) There is no standardized way of filling out the statistical form. The data filled in the form are of comparatively high haphazard. In the process of filling out the “Form on the Construction of Pollution Control Projects in Industrial Enterprises”, it is quite common that there is no data available in some items, or duplication in some items. In addition, there is no system on data certification. Therefore the resulting statistics on environmental protection investment have not accurately reflected the real situation.

3 Recommendations on the improvement of China’s statistical system of environmental protection investment

3.1 Clearly define the connotation of environmental protection investment and adjust the statistical scope of environmental protection investment

(1) The environmental protection investment should be clearly defined as a fixed assets investment with its scope and components being specified based on objective-oriented and effectiveness-oriented principles. (2) The investment in the treatment of industrial pollution sources and the “Santongshi” environmental protection investment should be merged as the investment of industrial pollution control. (3) The components of urban environmental infrastructure investment should be adjusted in which the investment in fuel gas, central heating, and urban landscape greening will be excluded, and, in the urban water drainage and sanitation aspect only the investment in waste water treatment plant and solid waste disposal is considered as environmental protection investment. (4) The investment in the capacity building of environmental supervision, rural environmental protection, construction of national key protected areas of ecological function and natural reserves should be included in the statistical scope of environmental protection investment.(5) The definition of circular economy and clean production

should be well established to prevent the arbitrary extension of the scope of environmental protection investment.

3.2 Develop scientific statistical system of environmental protection investment to reflect the real picture of input level of environmental protection

(1) Further clarify that the "Santongshi" environmental protection investment does not include investment in urban waste water treatment plan and solid waste disposal facilities. The investment in the treatment of existing industrial pollution sources should not be included in the "Santongshi" environmental protection investment. (2) The statistical methods for different types of environmental protection investment should be developed based on the adjusted statistical scope of environmental protection investment. The issues on the duplication and time inconsistency in the statistics of environmental protection investment could be addressed by drawing on the experience of the statistical method of fixed assets investment. (3) Improve the statistical system of the recurrent expenditure for environmental protection, making it comparable with that commonly exercised internationally. The pilot exercise of the improved statistical system should be conducted.

3.3 Improve the statistical system of environmental protection investment and standardize the statistics of environmental protection investment

(1) Address the issue of the dispersed management of the statistics of environmental protection investment by centralizing the management in each government department. (2) Improve the statistical system of environmental protection investment by redesigning the statistical form in which the components of environmental protection investment should be classified in terms of environmental media and industries, and the information on fund source and operation cost, etc should be added. The database of environmental protection investment should also be improved. (3) Establish the accounting system of environmental protection investment and quality control system of statistical data. The certification and checking of statistical data should be strengthened in order to improve the data quality and reflect the real situation of environmental protection investment. (4) Establish financial accounts for the environmental protection investment, environmental input, and environmental protection expenditure to facilitate the comparison with other countries. Standardize the method of collecting and issuing data on environmental protection investment. The indicators to be issued should be increased.

References

WANG Ziyu. Comparison and China's Innovation on Environmental Investment mechanism between China and America[J]. Journal of Anhui University.2001.(6):7.

HE Xudong, HOU Lisong, SUN Dongyu. Theoretical Study and Development on Environmental Investment[J].Sichuan Environment.1999(1):28.

SUN Dongyu, WANG Zhensheng, HE Xudong. Natural Capital and the Meaning of Environmental Investment[J].Environmental Protection.1999.5(5):38.

XU Xiang, TANG Shangying. Connotation and Philosophical Consideration on Ecological Investment[J]. Theory Monthly. 2005.No11:28-30.

WANG Jinnan, GE Chazhong,YANG Jintian. Environmental Financing Strategy[M].Beijing: China Environmental Science Press, 2003. 38-39.

WU Shunze, CHEN Bin, LU Yuantang. Analysis and Suggestion on Distortion of Environmental Protection Investment in China. China Population Resources and Environment[J].]2007.17(3).

Government intervened side payment schemes in Japan

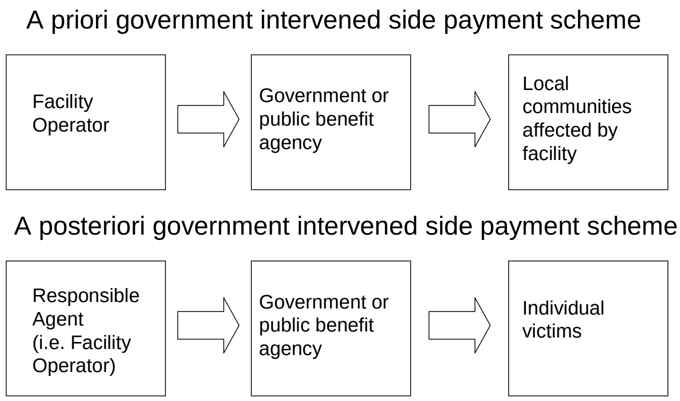
Hiroshi YOSHIDA[1]

Definitions, Objectives and Methods of this study

There are various government intervened side payment schemes (GISPSs) in Japan. GISPSs can be categorized into two types -- a priori type and a posteriori type.

A priori type GISPS is a scheme making a payment for communities of the local inhabitants to achieve acceptance of so-called NIMBY facility. Usually, the amount needed to make payments is borne by the facility operator and will be shifted to facility's customer. The government (or public benefit agents) collects funds from facility operator, and makes payments for community of the local inhabitants. The a priori type GISPSs are legislated for waste disposal and treatment facilities / electric power stations / nuclear facilities / dams and so on.

A posteriori type GISPS is a scheme to relieve victims damaged by business activities such as facility operation with burden of responsible agent such as facility operator. Under the a posteriori type GISPS, the government (or public benefit agents) collects funds from responsible agent, but basically makes a payments for individual victims, not for community of the local inhabitants. The a posteriori type GISPSs are applied for work accident / environmental pollution / medicine adverse side effect and so on.



Under GISPS of either type, some part of the costs is collected forcibly, another part relies on voluntary contributions. The most important difference between a priori type and a posteriori type is that under a priori type scheme the payments are paid collectively to community of the local inhabitants who would be potentially affected by facility operation, whereas under a posteriori type scheme payments are paid to the individual who really suffered by business activities.

In this paper I define "potential victims" as inhabitants or consumers who may be damaged

[1] Associate Professor, Faculty of Agriculture, Tokyo University of Agriculture and Technology
HALLA@CC.TUAT.AC.JP

by business activities (however, if they are lucky, they are able to escape from such damage). In other words, a potential victim is not yet damaged, but will be damaged in the future if he is doomed so. A priori type GISPS is the payment for potential victims, whereas a posteriori GISPS is the payment for real victims.

The purpose of this paper is to describe the legal system and actual situation of these GISPS and the function that GISPS carries out in Japan.

Examples of GISPS in Japan

1. A priori type GISPS

1-1 Artificial Reservoir Backyard Area Rehabilitation Act

This law was enacted in 1973 to reduce the disadvantage of the artificial reservoir backyard area and to activate the region. The purposes of this law are the following two points.

(a) Supporting the resident who had lived in submerged area and were resettled to stabilize their life and to improve welfare.

(b) Installing industrial infrastructure into the artificial reservoir backyard area, in where the apprehension of population decrease caused by reservoir construction is plausible.

The target of this system is water resources development project which cause more than 20 households submerged or more than 20hectares farmland submerged. Once a water resources development project is qualified, various infrastructure constructions (construction of the road, wastewater treatment, recreation facilities, communal facilities, and welfare facilities, etc.) will be undertaken in its backyard area. Costs of such projects are borne by the national government subsidy and the downstream beneficiaries (municipalities, water service operators, and electric power companies, etc.). As for 2010, 96 water resources development projects are qualified, 60 projects are completed, 14 projects are under construction, 22 projects are suspended to review their necessity.

This system has inherently contradicted feature. If the purpose of this system is totally achieved, population will increase and many industrial facilities will be introduced in backyard area of artificial reservoir. These successes of regional development may cause water quality deterioration in the reservoir.

1-2 Electric Power Plant Construction Promotion

This system consists of three laws (Electric Power Development Promoting Tax Act, Electric Power Development Promoting Special Budget Act, Power Plant Backyard Area Development Act). These laws were enacted in 1974, the next year of enacting Artificial Reservoir Backyard Area Rehabilitation Act.

The purpose of this law is promotion of construction of the power plant by paying subsidies to the region where electric power development project is planned. The cost of such payment is borne by electric power consumers (electric power development promoting tax, 375yen per 1,000kwh) .

The electric power companies collect this tax from their customers and pay to the government. The government delivers the subsidy to the region where the power plant is planned, constructed or operating.

Electricity cannot be accumulated, therefore, the expansion of demand forces electric power companies to construct new power plant. However, because the power plant needs vast building site, the plant is often constructed in sparsely populated area far from large cities where electric power is demanded.

The construction of the power plant may cause various adverse effects in the region. As for nuclear power plant, it is easily to see that the plant has potentially horrible danger. Thermal power plants or hydroelectric power plants also have disadvantages such as deterioration of ambient air quality, water quality or landscape. The profit of constructing the power plant mainly belongs to the region consuming the electric power and the disadvantage is remained in the region near construction site. Naturally enough, this situation may stimulate the protest campaign in the region where the power plant is planned. The purpose of this system is to conciliate the protest campaign by delivering subsidies to redistribute the benefit and disadvantage of the power plant construction.

The amount of this subsidy is 124.2 billion yen (2010 budget) and it is spent in construction of cultural facilities (e.g. museums, art gallery, etc.), sport facilities, public relations facilities and so on. These facilities will be used as shelter in the case of emergency accident of power plant. In principle this subsidy can't be spent in social infrastructure development.

1-3 Waste treatment and so on

Similar systems are introduced to the construction of radioactive waste treatment and disposal site, conventional (not radioactive) waste treatment and disposal site.

2. A posteriori type GISPS

2-1 Compensation for environmental pollution victims

Japanese rapid economic growth in 1950's and 1960's achieved many preferable results, but in the other side various undesirable social problems accompanied. Especially, serious problems to be called “kogai” (公害) occurred. The word “kogai” ("公害") consist of “公” and “害”. The letter "害" means damage. The letter “公” means “public” or “official”, but in the case of “kogai” (“公害”) it means public. So, the word “kogai” means public's damage. “Kogai” problems initially occurred from the middle 1950's or earlier, but they attracted strong social attention and sympathy in the latter half of 1960's. During latter half of 1960s, trials related in kogai were filed in succession, and they ended in win of the victim's side. 4 famous kogai-related trials (Kumamoto Minamata Disease, Niigata Minamata Disease, Toyama Itai-itai disease, Yokkaichi asthma) are called “4 representative kogai trials”. 4 representative kogai trials were all filed during latter half of 1960's, but Kumamoto Minamata disease or Toyama Itai-itai disease was incurred before 1955.

Early 1970s, the plaintiffs of kogai-related trials continued winning in the trials and social democratic political groups which cooperated with anti-kogai movement grew stronger and stronger. Facing this situation, the Japanese government decided to found the pollution-related health damage compensation (PRHDC) system in 1969 and expand in 1973 to tranquilize kogai victims.

The PRHDC system was applied to two class of cases; 1st class and 2nd class. The 1st class was applied to 41 heavy air-polluted regions. The 2nd class is applied to 5 cases, Minamata Diseases (Kumamoto and Niigata), Itai-itai Disease, and 2 cases of arsenic mine (Matsuo and Toroku).

In the case of both 1st and 2nd classes, persons certificated as victims suffered from "kogai" (in this case, i.e. environmental pollution) can receive formally determined amount of compensation (80% of average laborer wage), medical support and so on. When the victims died by disease related to environmental pollution, surviving family is paid pension and the cost of funeral ceremony. There is no difference between high income victims and low income victims. The companies which caused environmental pollution should bear the liability for the fund for these payments. A non-profit agency (Environmental Restoration and Conservation Agency, ERCA) was established, ERCA collects fund from liable companies and distribute it to certified victims or his/her surviving families.

As for 1st class of pollution (air pollution case), each factory's liability share was determined in proportion to the sulfur oxides (SOX) quantity which had emitted because the question which factory emitted the pollutants causing the victim's health damage could not be certainly resolved. Medical experts appointed by prefectural governor screened victims to certificate.

There are two presumptions about PRHDC system. First, the cause of asthma is not only air pollution. Under PRHDC system, when the resident living in specified heavy air-polluted areas for a long period suffered by asthma, then his disease was supposed to have been caused by air pollution. This presumption incurred another contradiction. If the residents living outside specified air-polluted area, even at a short distance from the specified area, then they can't receive payments under PRHDC.

Second, if there are many factories in one air-polluted area (it is ordinary situation), the question which factory caused asthma can't be resolved. Under PRHDC system, it is presumed that each factory caused health damage and should contribute to the compensation fund in proportion to the amount of sulfur oxides (SOx) which they emitted. This presumption also incurred another contradiction. The amount of SOx emitted from factories had decreased continuously and the ambient concentration of SOx also had fallen. But the number of asthma sufferers has increased because other pollutants instead of SOx, such as nitrogen oxides (NOx) or Suspended Particulate Matter (SPM), have worsened air pollution.

As described above, the PRHDC system inherently contains some theoretical difficulties.

And social circumstances around this system had been changed after 1980's. As wage rate rose and labor force saving technology became spread, the number of blue-collar workers diminished. The diminishing of blue-collar workers resulted in fall of influence of the trade unions and social democratic political parties. Because anti-kogai movements were strongly tied to social democratic political groups, when the power of social democratic political groups declined, the power of anti-kogai movements also weakened. The same time, there were some improvements about situations of environmental pollution, so environmental pollution problems attracted less public attention than when the situation had been more severe. About PRHDC, the 1st class (air pollution) regime was virtually abolished in 1989.

2-2 Compensation System for Medicine Adverse Effect

The GISPS like PRHDC are enacted related to adverse effect of medicine or vaccine injection. In other developed countries than Japan, adverse effect problems are treated as PL (Product Liability) issues, in contrast these problems are treated as GISPS in Japan because fundamental cause of these problems are unruly big business activities, which is the same characteristics with environmental pollution. And in Japan, medicine adverse effect case by which many people("公") were sacrificed("害") repeatedly happened. Thalidomide seal baby case (1961), SMON (Subacute Myelo Optico Neuropathy) case (1970), Chloroquine case (1979) and Hemophilia AIDS case (1985) are well known examples. As a result the liabilities of medical companies who produced medicine were strongly accused and they needed to evade trials and to tranquilize criticism of publics.

The GISPSs related to adverse effect of medicine are subdivided into several legislations listed as below.

(a) For victims of vaccine injection
(b) For victims of biology-derived medicine
(c) For victims of medicine produced from HIV polluted blood
(d) For victims of medicine produced from HCV (Hepatitis C virus) polluted blood
(e) Other case

These are classified by the characteristics of substances used in medical activity, not medical activity itself.

Under any legislation, the victims are able to receive payments if he/she is certificated as victim. The costs of payments are borne by companies which produce the medicine except for vaccine injection. As for vaccine injection, the costs of payments are borne by national and local government, so compensation system for victims of vaccine injection is incomplete system as GISPS. Pharmaceuticals and Medical Devices Agency (PMDA) collects the fund and distributes the payments. The amounts of payments are similar but there are some differences between legislations. Like PRHDC, there is no difference between high income victims and low income victims.

2-3 Asbestos and so on

Similar GISPS are introduced for victims by asbestos.

There are two precedents of GISPS. The first precedent is mandatory work accident insurance. The basic framework of GISPS (non-profit agency, funding, certification of victims, compensation, pension for surviving family and payments for funeral ceremony and so on) was induced from mandatory work accident insurance. The mandatory work accident insurance was enacted in 1927 as a part of mandatory health insurance and became independent legislation in 1947.

The second precedent is the relief system for atomic bomb victims of Hiroshima and Nagasaki enacted in 1957. Under the relief system for victims of atomic bombs, certificated victims are paid same amount of compensation regardless of the fact his/her income are high or low, which feature is different from mandatory work accident insurance.

The findings of this study

1. Existence of uncertainty is necessary precondition.

The existence of uncertainty of damage (what kind of damage will occur or who will be damaged) is the basic and necessary precondition of GISPS. Under existence of uncertainty it is unrealistic that the facility operator and potential victims make contract a priori which can deal with all situation which possibly will occur. If there is no damage compensation contract, intense protest campaign against "NIMBY" facility may be the optimal choice for potential victims to prevent damages. These intense protest campaigns will take very high transaction costs and in worst case the socially beneficial project would be canceled by intense protest.

2. The function of GISPSs

I'll summarize the two function of the GISPSs as below.

(1) Saving transaction costs to negotiate on damage compensation contract

(2) Redistributing profits gained from business activities to (potential or real) victims

The former function is related to efficiency, whereas the later is related to equity of income distribution.

Government intervention could supply socially acceptable criteria about compensation. The reason is that in democratic nation the government represents various groups in the nation. A victim has a ballot, other people have the same one ballot respectively. The existence of such criteria could decrease transaction costs.

On the other hand, unruly business activities causing victim's damage were thought unfair, so some scheme such as GISPS was needed to confiscate unfair profits and to redistribute them to the victims.

To some extent Marxian thinking influenced public's "fair" sentiment in Japan. It was thought "unfair" that the big business gain big profit by sacrificing many innocent people, as well as it was seemed to be "unfair" that the big business gain big profit by severely exploiting workers.

3. The reason why GISPS developed only in Japan (Japanese special condition)

There are some similar schemes like GISPS in other countries, but there is no country where various GISPSs developed as in Japan. I'll pointed out three reasons which explain why GISPSs developed largely only in Japan.

(1) Rapid economic growth and sudden outbreak of mass production / mass consumption

(2) Insufficiency of social welfare

(3) Ineffectiveness of legal procedure, especially trial

In postwar Japan, its economy grew very rapidly and the mass production and mass consumption were suddenly accomplished. They improved the quality of life of Japanese nationals but in the other hand mass production and mass consumption caused the "mass damage". But social welfare in Japan was very poor and the victims of mass damage were forced to live under the very miserable conditions.

In Japan the trials take many time and high costs. And victims can expect small amount for compensation even if they win the trial. In addition, because the responsible agents such as big corporation have lots of scientific knowledge, it'll be very difficult to prove the strict causality between business activities and victim's damage. As a result, the possibility that the victims will loss the trial can not be negligible. They are the reasons because more suitable procedure than unreliable trial was needed to relieve victims of mass damage.

References

Agency for Natural Resources and Energy. The outline of electric power plant construction promotion scheme., Center for Development of Power Supply Regions (Tokyo), 2009 (in Japanese)

Environmental Restoration and Conservation Agency. Handbook of Pollution Related Health Damage Compensation System., Environmental Restoration and Conservation Agency (Tokyo), 2009 (in Japanese)

Tsuru, Shigeto. The political economy of the environment: The case of Japan., Athlone Press(London), 1999.

Water Resources Environment Technology Center. Water resources vision: Towards 21th century., Taisei Publishing(Tokyo), 1999 (in Japanese)

The Optimal Environmental Tax and Urban Unemployment in a Small Open Dualistic Economy with Intersectoral Capital Mobility: Does Environmental Protection Reduce Urban Unemployment in the Long-run?[†]

Ichiroh Daitoh[*] Masaya Omote

Tohoku University

March 19, 2010

Abstract: This paper investigates how a rise in the urban pollution tax rate may affect urban unemployment and welfare in a small open Harris–Todaro (HT) model with intersectoral capital mobility. First, by formulating urban pollution as a dirty input in manufacturing, we find that an increase in the urban pollution tax rate can increase the level of urban unemployment even with intersectoral capital mobility. That is, the optimistic finding by Rapanos (2007) that environmental protection policy reduces urban unemployment in the long run does not always hold. Second, the (sub)optimal pollution tax rate under urban unemployment is *higher* than the Pigouvian tax rate (the marginal damage of pollution). This result opposes those of Beladi and Chao (2006) for a closed HT economy and of Tsakiris et al. (2008) for an open HT economy with sector-specific capital.

[†] This paper was presented at the Kanto Meeting of the Japan Society of International Economics in 2009 and the 2009 Fall Meeting of the Japanese Economic Association. We appreciate Professor Kenzo Abe (Osaka University), Taiji Furusawa (Hitotsubashi University), Ken-Ichi Akao (Waseda University) and Keisaku Higashida (Kansei Gakuin University) for their useful comments. Daitoh appreciate Sumitomo Foundation for providing "Kankyou Kenkyu Jyosei (Environmental Research Fund)" and the Japan Economic Research Fund for their financial supports.

[*] Department of International Economic Relations, Graduate School of International Cultural Studies, Tohoku University; 41 Kawauchi, Aoba-ku, Sendai-city, Miyagi, 980-8576, Japan; TEL&FAX: +81-22-795-7595. Email: idaito@intcul.tohoku.ac.jp

Key Words: Harris–Todaro model, industrial pollution, optimal pollution tax, urban unemployment
JEL Classification Numbers: O13, O18, Q56

1. Introduction

Since the beginning of this century, international cooperation between developed and developing countries for the preservation of the global environment has become more and more important. However, many developing countries have attempted to reduce domestic poverty through industrialization. Some developing countries, including China, India, Mexico, and Chile, have largely succeeded in it through urban industrial growth. As such, they have also suffered from degradation of the domestic environment due to urban industrial pollution and, in some cases, increased transboundary pollution (e.g., Beghin et al. (2002)). It thus appears necessary to implement environmental preservation policies not only in developed but also in developing economies. Therefore, it is of fundamental and practical importance to understand whether poverty reduction through industrialization is consistent with environmental preservation in a developing economy.

The recent literature on environmental preservation in developing economies has concentrated on urban unemployment as a form of poverty unique to these economies. In doing so, the focus of interest has been whether and under what conditions environmental policies reduces urban unemployment, often employing the Harris–Todaro (HT) (1970) model (Dean and Gangopadhyay, 1997; Chao et al., 2000; Daitoh, 2003; Beladi and Chao, 2006; Rapanos, 2007; Daitoh, 2008; Tsakiris et al., 2008).

In a closed HT model with sector-specific capital, Daitoh (2003) has derived the necessary and sufficient condition for a reduction in urban unemployment and a sufficient condition for welfare improvement. Daitoh (2003) showed that welfare always improves if the urban pollution tax rate is initially set in a sufficiently low range. Beladi and Chao (2006) investigated whether developing countries have a comparative advantage in pollution-intensive goods, as claimed by the 'pollution haven' hypothesis. For this purpose, they analyzed a closed HT model with intersectoral capital mobility, showing that a developing country have a comparative advantage in clean goods. Beladi and Chao (2006) also derived the optimal tax rate (the rate that leads to the optimal level of the preservation of raw materials) under urban unemployment, and found that this would be *lower* than the marginal damage of pollution (the Pigouvian tax rate) in a closed HT economy.

Given that modern developing countries are typically open economies with international trade in goods, it must be no less important to explore these issues in open HT models. Using a small open HT model with sector-specific capital, Daitoh (2008) focused on environmental protection and trade policy reform, elucidating under what conditions they are consistent with each other or work in opposite directions in improving urban unemployment and welfare. Tsakiris et al. (2008) showed that the optimal trade and environmental policy is the combination of free trade and environmental tax which is *lower* than the marginal damage of pollution. We could regard these approaches as showing the short-run effects, because capital is sector specific. In contrast, Rapanos (2007) analyzed small open HT models with both (short-run) sector-specific capital and (long-run) intersectoral capital mobility. Supposing that the pollution from the urban manufacturing production has a negative externality on agricultural productivity, Rapanos (2007) investigated the effects of a change in the production tax in urban manufacturing (as the first-best policy tool for environmental regulation). It was shown that the production tax may increase or decrease urban unemployment in the short run, while it necessarily decreases urban unemployment in the long run. At present, this rather optimistic conclusion appears to lie on the frontier of this issue. Indeed, if it does hold, development and environmental economists need not be concerned about environmental degradation in the long run when they pursue reductions in urban unemployment through industrialization.

This paper first investigates whether environmental protection policy always reduces the level of urban unemployment in a small open HT model with intersectoral capital mobility. The results are that an increase in the urban pollution tax rate, though it always lowers the ratio of urban unemployment, can raise the level of urban unemployment if the reduction in pollution increases the marginal product of labor (MPL) in urban manufacturing. What then is the reason for the difference in the findings of this analysis and the long-run outcome in Rapanos (2007)? In response, Rapanos (2007) assumes that the amount of pollution depends on the output level of urban manufacturing, while we formulate pollution as a factor of production (a dirty input). As often pointed out, especially in the trade and environment literature, formulating pollution as an input (Pethig, 1976; McGuire, 1982) and as a joint product of the good is theoretically equivalent. However, when it comes to examining the effects of environmental policy on labor employment or unemployment,[1] formulation as an input could be more appropriate because it can capture substitutability and complementarity among factors of production in greater detail.

As a second contribution, and unlike Rapanos (2007), this paper characterizes the optimal pollution tax rate under urban unemployment in a small open HT economy with intersectoral capital mobility. We show that the optimal pollution tax rate is *higher* than the Pigouvian tax rate (marginal damage of pollution). This contrasts with the results of Beladi and Chao (2006) for a closed HT economy and of Tsakiris et al. (2008) for a small open HT economy with sector-specific factors, where the optimal pollution tax rate is *lower* than the Pigouvian tax rate. The difference arises from whether the urban unemployment ratio increases (in a closed economy and in an open economy with sector-specific capital) or decreases (in an open economy with intersectoral capital mobility). Intuitively, when the urban unemployment ratio falls, environmental protection policy has the additional consequence that it weakens labor market distortion. If the pollution tax rate increases up to the Pigouvian tax rate, it

---

[1] Interest in the relation between the environment and labor employment is also found in, e.g., Renner (1991), Mehmet (1995), and Schweinberger and Woodland (2008).

improves welfare too little. Therefore, the welfare-maximizing pollution tax rate is higher than the Pigouvian tax rate because it can afford to strengthen its effect by enhancing labor market distortion. We can show this economic logic clearly by assuming that urban pollution (a dirty input) exerts a negative externality on consumers' utility, while in Rapanos (2007) it has a negative externality on agricultural productivity.

2. The Model

Consider a small open HT economy with intersectoral capital mobility. A rural product is the *numeraire* and the world market gives the relative price p of an urban manufactured good. In order to make clear the difference from Rapanos (2007), we use the same setting as his model in that urban manufacturing emits pollution and has no abatement activities while rural production does not generate pollution.[2] Unlike Rapanos, we assume that pollution exerts a negative externality on consumers' utility, not on agricultural productivity. This simplifies general equilibrium effects substantially, enabling us to show more clearly the economic logic for an increase in the level of urban unemployment.

In the urban manufacturing sector, the representative firm's production function $M(L^M, K^M, Z)$ satisfies the standard properties of a neoclassical production function and exhibits constant returns-to-scale (CRS) in labor L^M, capital K^M, and a 'dirty input' Z. A dirty input Z is any factor of production that can be regarded as generating pollution. Without loss of generality, we assume that each unit of a dirty input cause one unit of pollution. In this sense a dirty input can be identified with pollution. We assume, for simplicity, that the market for Z does not exist and that the government imposes a specific tax τ on the use of Z by firms.

In our analysis, the effects of a dirty input on the MPL in urban manufacturing, i.e., $\partial M_L / \partial Z = M_{LZ}$, play a crucial role, where the subscript represents the partial

---

[2] See a comment on the role of abatement activities in our model in section 5.

derivative. To make a concise analysis, we assume that the urban MPL rises as capital inputs increase ($M_{LK} > 0$). However, we impose no restrictions on the relations (the sign of M_{KZ}) between the marginal product of capital (MPK) and a dirty input.

Let us refer to examples of a dirty input Z in realistic situations, focusing on the impacts on the MPL. One could find a situation in which the machines Z that emit pollution are operated in factories together with clean capital goods K^M such as buildings, warehouses, paved roads and fences surrounding the factories. These machines may be equipments producing commodities or machines conveying finished products or intermediate materials within and among factories and warehouses (e.g., trucks and forklifts). In this example, Z exerts opposing effects on the MPL. First, use of Z tends to raise the MPL because these machines could improve the speed and intensity of workers. Second, it tends to lower the MPL because pollution due to the use of Z harms workers health and/or makes their working environment worse. If the first effect dominates (is dominated by) the second, a reduction in Z shifts the MPL curve downward (upward).[3] Furthermore, because the property of $M_{LZ} < 0$ is important in the following analysis, we present a more concrete example for it. In textile industry in developing countries workers often color cloths, staying in a pool of dye Z . Because Z is toxic and seriously damages workers' physical condition, the MPL tends to decrease during production. If workers come to use machines K^M that can dye cloths instead of working in a pool of dye, a reduction in Z shifts the MPL curve upward substantially.

The urban wage rate w^M is institutionally fixed and the rental rate of capital *r* is endogenously determined in the competitive domestic market. Given profit maximization, the value marginal product of each factor of production must equal its price:

---

[3] One could consider the other situation where K^M is production machines which do not emit pollution by themselves and Z is energy goods with pollution that are put into them (e.g. coal, petroleum or electricity generated by burning them). In this example, Z itself has no effect on the MPL ($M_{LZ} = 0$) while it clearly improves the MPK.

$$pM_L(L^M, K^M, Z) = w^M \ , \qquad (1)$$

$$pM_K(L^M, K^M, Z) = r \ , \qquad (2)$$

$$pM_Z(L^M, K^M, Z) = \tau \ . \qquad (3)$$

The representative rural firm's production function $A(L^A, K^A)$ satisfies standard neoclassical properties and exhibits CRS in labor L^A and capital K^A. The rural firm chooses K^A such that the MPK equals the rental rate of capital, and L^A to make the MPL equal the wage rate w^A:

$$A_K(L^A, K^A) = r \ , \qquad (4)$$

$$A_L(L^A, K^A) = w^A \ . \qquad (5)$$

The Harris–Todaro migration equilibrium condition (HT condition) then determines the labor allocation between rural and urban areas:

$$w^A = w^M L^M / [L^M + L^U] = w^M / [1 + \mu] \qquad (6)$$

where L^U is the level of urban unemployment and $\mu = (L^U / L^M)$ is the urban unemployment ratio.[4] The labor and capital allocations are:

$$L^A + L^M + L^U = L \ , \qquad (7)$$

$$K^A + K^M = K \ , \qquad (8)$$

where L and K are the respective labor and capital endowments. Given p, τ, w^M, K, and L, equations (1) to (8) determine the equilibrium values of the eight unknown variables r, w^A, L^A, L^M, K^A, K^M, Z, and L^U.[5]

The general equilibrium system is solved as follows. First, because the marginal product of each factor is homogeneous of degree zero, we can rewrite (1) to (3) as:

$$M_L(1, k^M, z) = l(k^M, z) = w^M / p \ , \qquad (1')$$

$$M_K(1, k^M, z) = \kappa(k^M, z) = r / p \ , \qquad (2')$$

---

[4] Put correctly, μ is the unemployment–employment ratio in urban areas. With a slight abuse of terminology, research using HT models traditionally refers to this as the 'urban unemployment ratio'.

[5] The present model so far has the same setting as that of Wang (1990). However, while Wang (1990) concentrated on the examination of the directions of change in factor prices (i.e., backward incidence) by pollution regulation, we engage in more extensive analyses of manufacturing employment and urban unemployment. Furthermore, we consider pollution externality on consumers' utility while Wang (1990) analyzed the model of production side only.

$$M_Z(1, k^M, z) = \delta(k^M, z) = \tau / p, \tag{3'}$$

where $k^M = (K^M / L^M)$ and $z = (Z / L^M)$. Equations (1') and (3') simultaneously determine the equilibrium values k^{M*} and z^* (an asterisk denotes the equilibrium value). Substituting these into (2'), we get r^*. The subsystem (1)–(3) is thus block recursive. Next, we define $a(k^A)$ by $A(L^A, K^A) = L^A A(1, K^A / L^A) = L^A a(k^A)$. Since the rural MPK is homogeneous of degree zero, (4) $a'(k^A) = r^*$ determines $k^{A*} = (K^A / L^A)^*$. Then (5) $a(k^{A*}) - k^{A*} a'(k^{A*}) = w^A$ determines w^{A*}. From (6) μ^* is determined. Given k^{M*}, k^{A*}, and μ^*, (7) $L^A + (1+\mu^*)\ L^M = L$ and (8) $k^{A*}L^A + k^{M*}L^M = K$ simultaneously determine L^{A*} and L^{M*}. Finally, we obtain $K^{A*} = k^{A*}L^{A*}$, $K^{M*} = k^{M*}L^{M*}$, $Z^* = z^* L^{M*}$ and $L^{U*} = \mu^* L^{M*}$.

3. Pollution Tax and Urban Unemployment

Let us investigate the effects of a rise in the urban pollution tax rate, focusing on how it may affect urban unemployment. Totally differentiating (1') and (3'), we obtain the comparative static results:

$$\frac{dz^*}{d\tau} = \frac{l_k(k^{M*}, z^*)}{pD} < 0, \tag{9}$$

$$\frac{dk^{M*}}{d\tau} = -\frac{l_z(k^{M*}, z^*)}{pD}. \tag{10}$$

For the concavity of $M(L^M, K^M, Z)$, $M_{LL}M_{ZZ} - M_{LZ}M_{ZL} > 0$ is assumed, which is equivalent to $D = l_k\delta_z - l_z\delta_k < 0$. From (9), pollution per urban worker (z^*) decreases because the urban MPL is increasing in capital input ($\partial M_L / \partial K^M = (l_k / L^M) > 0$). However, (10) implies that the urban capital–labor ratio k^{M*} may either increase or decrease, depending on whether the urban MPL increases or decreases with the fall in *Z*: k^{M*} increases if $l_z > 0$ holds, while k^{M*} decreases if $l_z < 0$ holds (recall that $\partial M_L / \partial Z = (l_z / L^M)$).[6]

[6] An example of CRS production function whose MPL is a decreasing function of a dirty input is $M = 3(L^M)^{1/3}(K^M)^{1/3}Z^{1/3} - 2(L^M)^{1/2}Z^{1/2}$.

Let us put forward an economic explanation for this process, taking advantage of the duality approach. We first note that the zero-profit condition $p = c(w^M, r, \tau)$ holds in urban manufacturing, where $c(w^M, r, \tau)$ is the unit cost function.[7] A rise in the urban pollution tax rate tends to increase the unit cost of urban manufacturing production. In order for the zero-profit condition to hold, the rental rate of capital in the urban area then needs to fall. That is, from (2'), $dr^* / d\tau = -[c_\tau(w^M, r, \tau) / c_R(w^M, r, \tau)] < 0$, where the subscript of $c(w^M, r, \tau)$ represents the corresponding partial derivative. Capital thus moves from urban to rural area, leading to a downward shift in the urban MPL curve. Since this tends to decrease urban employment, the direction of change in $k^{M*} = (K^M / L^M)^*$ is ambiguous. In the rural area, by contrast, because the capital-labor ratio rises ($dk^{A*} / d\tau = [1/a''(k^{A*})]\,[dr^* / d\tau] > 0$ by (4)), the rural MPL curve shifts upward and the rural wage rate rises. During the urban-to-rural migration process, the rural wage rate declines along the rural MPL curve. Nevertheless, the equilibrium rural wage rate is higher than that in the initial equilibrium ($dw^{A*} / d\tau = -k^{A*}a''(k^{A*})[dk^{A*} / d\tau] > 0$ by (5)). This implies that the urban unemployment ratio μ^* always declines ($d\mu^* / d\tau = -[(1+\mu^*)/w^{A*}]\,[dw^{A*} / d\tau] = -[k^{A*} / w^M][c_\tau / c_R] < 0$ by (6)). In addition, (6) implies that when the upward shift of the rural MPL curve is smaller and/or the rural MPL curve is steeper,[8] the decline in μ^* is smaller. If its decline is small enough relative to an increase in L^{M*}, $L^{U*} = \mu^* L^{M*}$ increases.

What then determines how much L^{M*} changes? Totally differentiating (7) and (8), regarding μ^*, k^{A*}, and k^{M*} as exogenous parameters, we find

$$\frac{dL^{A*}}{d\tau} = \frac{1}{\Delta}\left\{-k^{M*}L^{M*}\frac{d\mu^*}{d\tau} + (1+\mu^*)L^{A*}\frac{dk^{A*}}{d\tau} + (1+\mu^*)L^{M*}\frac{dk^{M*}}{d\tau}\right\} \qquad (11)$$

$$\frac{dL^{M*}}{d\tau} = \frac{1}{\Delta}\left\{k^{A*}L^{M*}\frac{d\mu^*}{d\tau} - L^{A*}\frac{dk^{A*}}{d\tau} - L^{M*}\frac{dk^{M*}}{d\tau}\right\} \qquad (12)$$

---

[7] We can confirm from (1)–(3) that the first-order conditions for cost minimization are satisfied, i.e., the relative factor price must equal the marginal rate of technical substitution.

[8] Because the rural wage rate declines more rapidly, a smaller number of people will emigrate from urban areas until the expected wage rates are equalized. The level of urban unemployment will then increase.

Under Assumption 1 below, $\Delta = k^{M*} - (1+\mu^*)k^{A*} > 0$ holds.

Assumption 1: $\dfrac{K^M}{L^M + L^U} > \dfrac{K^A}{L^A}$ holds in equilibrium.

It means that the urban area is more capital-abundant than the rural area. This capital abundance condition is the necessary and sufficient condition for stability of the HT equilibrium derived by Neary (1981). Several years later Neary (1988) showed that when a third factor of production (land) is used in agriculture it is no longer either necessary or sufficient condition for stability. Funatsu (1988) showed that in the same situation this condition is not a necessary but a sufficient condition for stability if the normality property of factors of production is assumed (i.e., each factor's marginal productivity diminishes with an additional input of that factor but is non-decreasing with an additional input of another factor). In our model, by contrast, a third factor (a dirty input) is used in urban manufacturing. Given the price of a dirty input, the capital abundance condition by Neary (1981) is not a necessary but a sufficient for stability of HT equilibrium in our model (see Appendix 1).[9]

Let us proceed to examine changes in urban pollution and unemployment. Given $d\mu^*/d\tau < 0$ and $dk^{A*}/d\tau > 0$, the signs of (11) and (12) depend on $dk^{M*}/d\tau$. We separate two cases. First, we consider the case of $l_z > 0$, where $dk^{M*}/d\tau > 0$ holds. Then L^{A*} increases and L^{M*} decreases. Thus $K^{A*}=k^{A*}L^{A*}$ increases while $Z^*=z^*L^{M*}$ and $L^{U*}=\mu^*L^{M*}$ decrease. More precisely, by differentiating $Z^*=z^*L^{M*}$, we obtain

$$\frac{dZ^*}{d\tau} = \frac{L^{M*}}{pD}\left[l_k + z^* l_z\right] + \frac{z^*}{\Delta}\left[k^{A*}L^{M*}\frac{d\mu^*}{d\tau} - L^{A*}\frac{dk^{A*}}{d\tau}\right] \tag{13}$$

Given $D < 0$, $l_k > 0$, $\Delta > 0$, $d\mu^*/d\tau < 0$ and $dk^{A*}/d\tau > 0$, we get $dZ^*/d\tau < 0$ under $l_z > 0$. Therefore, a rise in the urban pollution tax rate reduces both the level of urban unemployment and pollution from urban manufacturing. This is qualitatively the same

---

[9] The capital abundance condition is not sufficient for stability in Rapanos' (2007) model with intersectoral capital mobility. Tawada and Nakamura (2009) show that a sufficient condition is the opposite (the urban area is more *labor*-abundant than the rural area) in their HT model with intersectoral capital mobility, where urban production exerts negative externalities on agriculture and the adjustment of natural environment takes much longer time than those of capital and labor.

result as Rapanos (2007) in that environmental protection is consistent with a reduction in the long-run urban unemployment.

Second, consider the case of $l_z < 0$, where $dk^{M*}/d\tau < 0$ holds. Then L^{A*} may decrease and L^{M*} may increase. If the effect of $l_z < 0$ is strong enough, $L^{U*} = \mu^* L^{M*}$ increases. We will elucidate that L^{U*} may increase even if Z^* decreases. When $Z^* = z^* L^{M*}$ decreases, L^{M*} can increase at a rate lower than the declining rate of z^*. On the other hand, $L^{U*} = \mu^* L^{M*}$ rises if L^{M*} increases at a rate higher than the declining rate of μ^*. We should note that how much μ^* declines depends on the properties of rural technology (i.e., upward shift and steepness of the rural MPL curve), while the change in z^* is determined only by the urban manufacturing technology (independent of rural technology). Therefore, a rise in the urban pollution tax rate may increase the level of urban unemployment, even if it decreases urban pollution. This implies that the optimistic result obtained by Rapanos (2007) may not hold. That is, environmental protection policy may aggravate urban unemployment even in the long run when capital is mobile between rural and urban areas.

Let us now derive the necessary and sufficient condition for an increase in L^{U*}.[10] Since it is difficult to derive a general condition for it, we confine ourselves to the benchmark case in which urban production remains unchanged (i.e., no scale effect). This enables us to show that what plays a crucial role is the substitutability and complementarity among factors of production. First, totally differentiating $L^U = \mu c_W(w^M, r, \tau)M$ and using $dM^*/d\tau = 0$, we obtain

$$\frac{dL^{U*}}{d\tau} = \left[\frac{L^{U*}}{\tau}\right]\left\{\eta + \varepsilon_{LZ} - \varepsilon_{LK}\left[\frac{\varepsilon_{KZ}}{\varepsilon_{ZK}}\right]\right\} \tag{14}$$

where $\eta = (\tau/\mu)(d\mu/d\tau)$ is the elasticity of urban unemployment ratio with respect to a pollution tax rate and ε_{ij} $(i, j = L^M, K^M, Z)$ is the cross elasticity of factor i with respect to factor j (see Appendix 2 for the derivation). In our model $\eta < 0$ holds and $\varepsilon_{LK} \equiv (r/c_W)(\partial c_W/\partial r) > 0$ is assumed as a natural property corresponding

---

[10] Daitoh appreciate Professor Kenzo Abe for his insightful discussions concerning this analysis. All responsibilities are ours, however, because the present analysis is different from the one in his comment.

to the assumption of $M_{LK} > 0$.[11] Because $c_{R\tau} = c_{\tau R}$ holds by Young's theorem, $\varepsilon_{KZ} \equiv (\tau / c_R)(\partial c_R / \partial \tau)$ and $\varepsilon_{ZK} \equiv (r / c_\tau)(\partial c_\tau / \partial r)$ have the same sign. However, the sign of $\varepsilon_{LZ} \equiv (\tau / c_W)(\partial c_W / \partial \tau)$ $= (\tau / L^M)(\partial L^M / \partial \tau)$ is ambiguous. If $\varepsilon_{LZ} < 0$ holds (L^M is complementary to Z), a rise in τ necessarily decreases L^{U*}. If $\varepsilon_{LZ} > 0$ is large enough (L^M is a sufficiently close substitute to Z), a rise in τ increases L^{U*}. The level of urban unemployment increases iff the cross elasticity of labor with respect to a dirty input in urban manufacturing is so large that $\varepsilon_{LZ} > \varepsilon_{LK}(\varepsilon_{KZ} / \varepsilon_{ZK}) - \eta \, (>0)$ holds. We summarize the results in the next proposition.

Proposition 1 (Pollution Tax and Urban Unemployment): *Suppose that an urban pollution tax rate is raised in a small open dualistic economy with intersectoral capital mobility. Under Assumption 1, (i) the level of urban unemployment declines if a reduction in pollution leads to a downward shift in the urban MPL curve. However, (ii) the level of urban unemployment may rise if the reduction in pollution leads to an upward shift in the urban MPL curve, even though urban pollution decreases. (iii) In the benchmark case where urban manufacturing production remains unchanged, the level of urban unemployment increases iff* $\varepsilon_{LZ} > \varepsilon_{LK}(\varepsilon_{KZ} / \varepsilon_{ZK}) - \eta$ *(>0) holds.*

Let us comment briefly on how an analysis differs if urban pollution exerts a negative externality not on consumers' utility but on agricultural productivity, as in Rapanos (2007). Suppose that the rural production function is $A = g(Z)A(L^A, \ K^A)$ with externality term $g'(Z) < 0$. Given that (1)-(3) are block recursive, w^{A*}, L^{A*} and K^{A*} are a function of μ and L^M by (6), (7) and (8). Thus $w^{A*} = g(z^* L^M)$ $A_L(L^{A*}, K^{A*})$ and $r^* = g(z^* L^M)$ $A_K(L^{A*}, K^{A*})$ determine μ^* and L^{M*} simultaneously. Since the direction of change in μ^* as well as that in L^{M*} turns out ambiguous, $L^{U*} = \mu^* L^{M*}$ can either rise or decline. This basic result survives though the analysis is much more complicated. (A detailed analysis is available on request.)

---

[11] We do not mean that $\varepsilon_{LK} > 0$ can be derived from $M_{LK} > 0$. Rather, we assume the former because it turns out difficult to find a simple logical relation between them.

4. Welfare-maximizing Pollution Tax under Urban Unemployment

We now explore the (sub)optimal pollution tax rate under urban unemployment. Let us first derive the change in GDP. Differentiating $G = A + pM$ and using $dp = 0$, we can represent the change in GDP in terms of the changes in the urban unemployment ratio and in a dirty input (see Appendix 3 for the derivation):

$$\frac{dG}{d\tau} = -\left(\frac{w_M L_M}{1+\mu}\right)\frac{d\mu}{d\tau} + \tau\frac{dZ}{d\tau}. \tag{15}$$

While a reduction in urban unemployment ratio ($d\mu^* / d\tau < 0$) tends to increase GDP, a change in a dirty input (representing the effect on manufacturing production) can either increase or decrease GDP. First, when $l_z > 0$ holds or when the effect of $l_z < 0$ is weak, $dZ^* / d\tau < 0$ holds. If this effect is weak, GDP increases. Second, if the effect of $l_z < 0$ is strong enough, $dZ^* / d\tau > 0$ holds and GDP increases.

Next, we assume that the representative consumer's utility function is strictly quasi-concave and homothetic in rural and manufactured good consumption, given pollution Z. Then, we have the expenditure function $E(p, Z, U)$, which is linear in U. The government transfers pollution tax revenue to consumers in a lump-sum fashion. Thus aggregate expenditure equals GDP.

Let us now derive the welfare-maximizing pollution tax rate τ^O. Totally differentiating $E(p,Z,U) = G$ with $dp = 0$ and dividing the result by $d\tau$, we get:

$$E_Z(p,Z,U)\frac{dZ}{d\tau} + E_U(p,Z,U)\frac{dU}{d\tau} = \frac{dG}{d\tau}. \tag{16}$$

Substituting (15) yields:

$$E_U\frac{dU}{d\tau} = (\tau - E_Z)\frac{dZ}{d\tau} - \left(\frac{w^M L^M}{1+\mu}\right)\frac{d\mu}{d\tau}. \tag{17}$$

The welfare-maximizing pollution tax rate τ^O must satisfy $dU/d\tau = 0$. Therefore:

$$\tau^O = E_Z + \frac{w_M L_M}{1+\mu}\left(\frac{d\mu/d\tau}{dZ/d\tau}\right). \tag{18}$$

One could confirm that τ^O actually maximizes utility if we focus on the natural case where $dZ^*/d\tau < 0$ holds. Eliminating E_Z in (17) using (18), we get:

$$E_U\frac{dU}{d\tau} = (\tau - \tau^O)\frac{dZ}{d\tau}. \tag{19}$$

With $E_U > 0$, $dU/d\tau > 0$ holds in the range $\tau \in [0, \tau^O]$, while $dU/d\tau < 0$ holds in the range $\tau \in [\tau^O, +\infty)$. Thus, welfare is certainly maximized at τ^O.[12] We can derive the next proposition from (18).

Proposition 2: *In a small open dualistic economy with intersectoral capital mobility, the (sub)optimal pollution tax rate* τ^O *under urban unemployment is higher than the Pigouvian tax rate represented by the marginal damage of pollution* E_Z.

This is a new result. While Beladi and Chao (2006) characterized the optimal pollution tax rate using a similar formula to (18), their model is of a closed HT economy. Tsakiris et al. (2008) also derived it in a small open HT model with sector-specific factors. They showed that a rise in the urban pollution tax rate *raises* the urban unemployment ratio ($d\mu^* / d\tau > 0$) and that the optimal urban pollution tax rate is *lower* than the Pigouvian tax rate. Intuitively, because a rise in the urban unemployment ratio implies the enhancement of labor market distortions, the optimal pollution tax rate should be *lower* so that this distortive effect weakens. In contrast, we consider, as in Rapanos (2007), a small open HT economy with intersectoral capital mobility.[13] A rise in the urban pollution tax rate *lowers* the urban unemployment ratio ($d\mu^* / d\tau < 0$), implying that it *weakens* the labor market distortions. Therefore, the optimal pollution tax rate should be *higher* than the Pigouvian tax rate, because it can afford to strengthen the labor market distortions.

One may wonder whether the labor market distortions really weaken, in spite of the fact that the level of urban unemployment increases. In order to understand this point, recall that the HT economy has two distinct labor market distortions. First, institutionally fixed high urban wage rate makes manufacturing employment too small. Second, the HT condition makes rural-to-urban migration excessive, inducing urban unemployment. The level of urban unemployment only represents the second

[12] If $dZ^* / d\tau > 0$ holds, τ^O minimizes welfare. In order to discuss the optimal pollution tax, we need to confine ourselves to the natural case above.

[13] Rapanos (2007) did not explicitly derive the movement of urban unemployment ratio.

distortion. It is well known in research on HT models that the overall welfare effect due to both distortions is captured by a change in the urban unemployment ratio. In this sense, we can interpret the change in μ as concisely representing the labor market distortions in this economy.

Relation to Previous Studies

Finally, we discuss the relationships between our analysis and previous work concerning optimal environmental policy in HT models. Dean and Gangopadhyay (1997) and Chao et al. (2000) discussed the optimal environmental regulation in closed and small open three-good HT models with an intermediate good whose production causes environmental damage (timber is a typical example).

Chao et al. (2000) showed that an increase in the preservation of raw materials leads to a rise in the urban unemployment ratio in a closed HT economy. However, while Chao et al. (2000, p. 45) derived the optimal level of preservation of raw materials (eq. (18)), they did not explicitly address the relation between the optimal policy and labor market distortion. They also showed that in a small open HT economy, the preservation of raw materials did not result in additional urban unemployment. This is because of the special structure of their three-good model. Because of this, they only mentioned that the optimal level of preservation is higher under free trade than no trade (Chao et al. 2000, p. 47).

Dean and Gangopadhyay (1997) discussed optimal production and export taxes on an intermediate good whose production causes environmental damage in a small open HT model. In the short run, optimal production and export taxes (interpreted as environmental taxes) are *less* than the value of marginal environmental damage that prevails under free trade. In the long run, however, these taxes are *greater* than the value of marginal environmental damage that prevails under free trade. Dean and Gangopadhyay (1997) gave detailed economic explanations for these results. Unfortunately, however, the more complicated structure of their three-good HT model made it difficult to specify (at least for the readership) the crucial factor determining the direction of the optimal environmental taxes. Because our model is simpler, we can clearly show that these opposing findings come from the difference in the direction of change in the urban unemployment ratio. In other words, among the many possible explanations put forward by Dean and Gangopadhyay (1997, pp. 334–335), what was crucial in the determination of the suboptimal environmental taxes is the statement that the production and export taxes aggravate urban unemployment in the short run while they alleviate it in the long run. This is clearly consistent with our findings.

Recently, Tsakiris et al. (2008) have shown in a small open HT model with two final goods that the optimal trade and environmental policy is the combination of free trade and environmental tax which is *lower* than the marginal damage of pollution (Proposition 2). They also point out that the higher emission tax aggravates the urban unemployment ratio (p.5) and that it pays to reduce the emission tax in order to account for its detrimental impact on unemployment (p.6). Even so, our opposing result is a new finding, because our model is of intersectoral capital mobility while their model is of sector-specific factors.

5. Concluding Remarks

We investigated how a rise in the urban pollution tax rate may affect urban unemployment and welfare in a small open Harris–Todaro (HT) model with intersectoral capital mobility by formulating pollution as a dirty input. First, we found that a rise in the urban pollution tax rate can *raise* the level of urban unemployment, even under intersectoral capital mobility. That is, the rather optimistic result by Rapanos (2007) does not always hold, such that environmental protection policy necessarily reduces the level of urban unemployment in the long run. Second, the (sub)optimal pollution tax rate under urban unemployment in a small open HT economy with intersectoral capital mobility is *higher* than the Pigouvian tax rate (the social marginal damage of pollution). This result opposes those of Beladi and Chao

(2006) for a closed HT economy and of Tsakiris et al. (2008) for a small open HT economy with sector-specific capital.

Before concluding, let us remark on the setting of the present model. We assume away abatement activities in the urban area that Beladi and Chao (2006) incorporated in their model. The presence of abatement activities appears desirable for their purpose, because these activities tend to increase labor employment in urban manufacturing and thus reduce the urban unemployment ratio. Beladi and Chao (2006) show that even in this setting, the urban unemployment ratio unambiguously increases, not declines. In our model, on the contrary, the urban unemployment ratio unambiguously declines with a rise in the urban pollution tax rate. The introduction of urban abatement activities would then only enhance the qualitative result.

Appendix 1: Stability Condition of HT Equilibrium

We show that Assumption 1 is a sufficient (not a necessary) condition for local stability of HT equilibrium, by following the method of Funatsu (1988). Note that the block recursive structure of (1)-(3) is useful for the investigation.

The movement of labor between two areas is captured by $\dot{L}^A = \alpha\left\{w^A - w^M L^M / [L^M + L^U]\right\}$ ($\alpha > 0$), where a dot represents a time derivative. Given τ, the subsystem (1)-(3) determine (k^{M*}, z^*, r^*). Using $L^M = (K - K^A)/k^{M*}$ and (7), we obtain:

$$\dot{L}^A = \alpha\left\{w^A - \frac{w^M[K-K^A]}{k^{M*}[L-L^A]}\right\} = \Gamma(L^A, K^A) \tag{A1.1}$$

The movement of capital between two sectors is captured by

$$\dot{K}^A = \beta[A_K(L^A, K^A) - r^M] = \Lambda(L^A, K^A) \qquad \beta > 0 \tag{A1.2}$$

where A_K is the rental rate of rural capital while r^M is that of urban capital. Given (1)-(3), $r^M = r^*$ is constant. We define the Jacobian matrix of the linearlized system of (A1.1) and (A1.2) as J. Each element of J is

$$\Gamma_L = \alpha\left\{A_{LL}(L^A, K^A) - \frac{w^M[K-K^A]}{k^{M*}[L-L^A]^2}\right\} < 0,$$

$$\Gamma_K = \alpha\left\{A_{LK}(L^A, K^A) + \frac{w^M}{k^{M*}[L-L^A]}\right\} > 0$$

$$\Lambda_L = \beta A_{KL} > 0\,, \qquad \Lambda_K = \beta A_{KK} < 0$$

where the subscript represents the partial derivative w.r.t. L^A and K^A. Because $Trace.J = \Gamma_L + \Lambda_K < 0$ always holds, we explore a condition for

$$Det.J = \alpha\beta\left\{[A_{LL}A_{KK} - A_{LK}A_{KL}] - \frac{w^M}{k^{M*}[L-L^A]}\left[\frac{K-K^A}{L-L^A}A_{KK} + A_{KL}\right]\right\} > 0\,.$$

Since $A_K(L^A, K^A)$ is homogeneous of degree zero, the Euler's theorem yields $A_{KL}L^A + A_{KK}K^A = 0$. Eliminating A_{KL}, we obtain

$$Det.J = \alpha\beta\left\{[A_{LL}A_{KK} - A_{LK}A_{KL}] - \frac{w^M A_{KK}}{k^{M*}[L-L^A]}\left[\frac{K^M}{L^M + L^U} - \frac{K^A}{L^A}\right]\right\}$$

For the concavity of $A(L^A, K^A)$, $A_{LL}A_{KK} - A_{LK}A_{KL} > 0$ is assumed. With $A_{KK} < 0$, Assumption 1 turns out to be a sufficient condition for $Det.J > 0$.

Appendix 2: Derivation of (14)

Totally differentiating $L^U = \mu c_W(w^M, r, \tau)M$ and using $dM^*/d\tau = 0$, we obtain

$$\begin{aligned}
dL^U/d\tau &= (d\mu/d\tau)c_W M + \mu M\left[c_{WR}(dr/d\tau) + c_{W\tau}\right] \\
&= (d\mu/d\tau)c_W M + \mu M\left[c_{W\tau} - c_{WR}(c_\tau/c_R)\right] \\
&= \mu c_W M\left\{(d\mu/d\tau)(1/\mu) + \left[(c_{W\tau}/c_W) - (c_{WR}/c_W)(c_\tau/c_R)\right]\right\} \\
&= (L^U/\tau)\left\{(\tau/\mu)(d\mu/d\tau) + \tau\left[(c_{W\tau}/c_W) - (c_{WR}/c_W)(c_\tau/c_R)\right]\right\} \\
&= (L^U/\tau)\left\{\eta + \varepsilon_{LZ} - \varepsilon_{LK}[\varepsilon_{KZ}/\varepsilon_{ZK}]\right\}
\end{aligned}$$

Appendix 3: Derivation of Change in GDP (15)

The changes in the urban unemployment ratio and pollution can represent the change in GDP. Totally differentiating $G = A + pM$ yields:

$$dG = dA + pdM = [A_L dL^A + A_K dK^A] + p[M_L dL^M + M_K dK^M + M_Z dZ]\,.$$

Substituting (1)–(5) into this, we obtain:

$$dG = w^A dL^A + r[dK^A + dK^M] + w^M dL^M + \tau dZ\,.$$

Using (6) and $dK^A + dK^M = 0$ by (8), we obtain:

$$dG = w^M[L^M/(L^M + L^U)]dL^A + w^M dL^M + \tau dZ\,.$$

Rearranging the terms using (7) yields:

$$dG = \frac{L^M}{L^M + L^U} w^M [-dL^M - dL^U] + w^M dL^M + \tau dZ$$

$$= \frac{w_M [L^U dL^M - L^M dL^U]}{L^M + L^U} + \tau dZ = \frac{w^M [(L^U / L^M) dL^M - dL^U]}{1 + (L^U / L^M)} + \tau dZ \, .$$

Substituting $dL^U = \mu dL^M + L^M d\mu$, we obtain (15).

References

Beghin, John, David Roland-Holst, and Dominique van der Mensbrugghe (eds.), Trade and the Environment in General Equilibrium: Evidence from Developing Economies, Dordrecht: Kluwer Academic Publishers, 2002.

Beladi Hamid and Chi-Chur Chao, "Environmental Policy, Comparative Advantage, and Welfare for a Developing Country," Environment and Development Economics 11 (2006): 559-568.

Chao, Chi-Chur, Joe R. Kerkvliet, and Eden S. H. Yu, "Environmental Preservation, Sectoral Unemployment, and Trade in Resources," Review of Development Economics 4 (2000): 39–50.

Daitoh, Ichiroh, "Environmental Protection and Urban Unemployment: Environmental Policy Reform in a Polluted Dualistic Economy," Review of Development Economics 7 (2003): 496–509.

Daitoh, Ichiroh, "Environmental Protection and Trade Liberalization in a Small Open Dual Economy," Review of Development Economics 12(4) (2008): 728–736.

Dean, Judith M., and Shubhashis Gangopadhyay, "Export Bans, Environmental Protection, and Unemployment," Review of Development Economics 1 (1997): 324–336.

Funatsu, Hideki, "A Note on the Stability of the Harris-Todaro Model with Capital Mobility," Economica 55 (1988): 119-121.

Harris, John R. and Michael P. Todaro, “Migration, Unemployment and Development: A Two-Sector Analysis,” American Economic Review 60 (1970): 126–142.

McGuire, Martin C., “Regulation, Factor Rewards, and International Trade,” Journal of Public Economics 17 (1982): 335–354.

Mehmet, Ozay, “Employment Creation and Green Development Strategy,” Ecological Economics 15 (1995): 11–19.

Neary, Peter, “On the Harris–Todaro Model with Intersectoral Capital Mobility,” Economica 48 (1981): 219–234.

Neary, Peter, “Stability of the Mobile-capital Harris–Todaro Model: Some Further Results,” Economica 55 (1988): 123-127.

Pethig, Rüdiger, “Pollution, Welfare, and Environmental Policy in the Theory of Comparative Advantage,” Journal of Environmental Economics and Management 2 (1976): 160–169.

Rapanos, Vassilis T., “Environmental Taxation in a Dualistic Economy,” Environment and Development Economics 12 (2007): 73-89.

Renner, Michael, Jobs in a Sustainable Economy, Worldwatch Paper 104, Washington DC: Worldwatch Institute, 1991.

Schweinberger, Albert G., and Alan D. Woodland, “The Short and Long Run Effects of Tied Foreign Aid on Pollution Abatement, Pollution and Employment: A Pilot Model,” Journal of Environmental Economics and Management 55 (2008): 310–325.

Tawada, Makoto, and Azusa Nakamura, “Environment and the Harris and Todaro Paradox,” in Kamihigashi, Takashi, and Laixun Zhao (eds.), International Trade and Economic Dynamics: Essays in Memory of Koji Shimomura, Heidelberg Berlin: Springer-Verlag, 2009: 87-99.

Tsakiris, Nikos, Panos Hatzipanayotou and Michael S. Michael, “Pollution, Capital Mobility and Tax Policies with Unemployment”, Review of Development Economics 12 (2008): 223–236.

Wang, Leonard, “Unemployment and the Backward Incidence of Pollution Control”, Journal of Environmental Economics and management 18 (1990): 292-298.

E-Waste Recycling Systems and Sound Circulative Economies in East Asia: A Comparative Analysis of Systems in Japan, South Korea, China and Taiwan

Sung-in Na[1] **and Soo-cheol Lee** [2,*]

[1] Hiroshima Shudo University, 1-1-1 Ozukahigashi, Asaminamiku, Hiroshima 731-3195, Japan; E-Mail: nasungin@shudo-u.ac.jp

[2] Meijo University, 1-501 Shiogamaguchi Tenpark-ku, Nagoya, Aichi 468-8502, Japan

* Author to whom correspondence should be addressed; E-Mail: slee@ccmfs.meijo-u.ac.jp; Tel.: +81-52-832-1151; Fax: +81-52-833-4767.

Abstract: The main purpose of this paper is to review and compare E-waste management systems operating in East Asian countries in efforts to identify future challenges facing the circulative economies in the region. The first topic of this paper is cost sharing (physical and financial) as applied to the various stakeholders, including producers, consumers, local governments and recyclers, in the E-waste management systems. The second topic is the environmental and economical impacts of these E-waste management systems on recycling technology, trans-boundary movement of E-wastes and Design for Environment (DfE). The final topic is the possibility for international cooperation in the region in terms of E-waste management systems. The authors' preliminary result is that the E-waste management systems operating in these East Asian countries have contributed to extended producer responsibility and DfE to some extent, but many challenges remain in their improvement through proper cost sharing among the stakeholders. It is also clear that the cross-border transfer of E-wastes cannot be resolved by one nation alone, and thus international cooperation will be indispensable in finding a suitable solution.

Keywords: E-waste recycling; extended producer responsibility; East Asia; circulative economy

List of Abbreviations

DfE: Design for Environment
DfR: Design for Recycling
EPR: Extended Producer Responsibility
EU: European Union
KAEE: Korean Association of Electronics Environment
KFEM: Korean Federation for Environmental Movement
OECD: Organization for Economic Cooperation and Development
REACH: Registration, Evaluation, Authorization and Restriction of Chemicals
RFMB: Recycling Fund Management Board
RoHS: Restriction of Hazardous Substances Directive

WEEE: Waste Electrical and Electronic Equipment

1. Introduction

This study addresses issues relating to the recycling of home electric and electronic appliances, a typical mainstay commodity of modern affluent societies. Here we define either waste or used home electric and electronic appliances as E-waste. By analyzing the recycling systems of E-waste in Japan, South Korea, China and Taiwan, in terms of the background to their adoption as well as their similarities and differences, we aim to evaluate the relevant policies and identify the future challenges facing the promotion of circulative economies in East Asia. Specifically, we will analyze the roles (separation, collection and recycling) and responsibilities (financial and physical) of each nation's E-waste disposal and recycling systems according to stakeholder (producer, consumer, central and local government) in order to clarify each system's characteristics and the extent of applying the Extended Producer Responsibility (EPR) [1].

The East Asia region, particularly Japan, South Korea, China and Taiwan, is a major consumer of home electric and electronic appliances, while also comprising a considerable global share of production and export. In addition, the increasing volume of trade in E-wastes in East Asian nations and the accompanying environmental impact have attracted attention in recent years [2,3]. The disposal of E-wastes is therefore not limited to a single nation in East Asia, but instead needs to be addressed as a regional issue. Some important studies analyzed East Asian nation's E-waste recycling systems with a focus on the responsibilities (physical and financial) of stakeholders [4-6]. In light of these previous studies, we have conducted our analysis with an emphasis on the content and stakeholder-based cost burden of recent new systems, the incentives to each stakeholder in terms of E-waste collection and recycling, and the possibility of cooperation on relevant policies among East Asian nations.

In the next section, we will consider the background of the reason that the EPR is applied to the policy design of E-waste recycling, not only from the perspective of domestic factors, but also from factors such as recycled resource trade in East Asia. In section 3, we will outline and characterize policies relating to E-waste recycling in East Asia as well as undertake a comparative analysis. In section 4, based on the results of the comparative analysis, we will outline the challenges facing the promotion of circulative economies and the potential for cooperation to find solutions to these challenges in this region.

2. Background to Introduction of E-Waste Recycling Systems

In this section, we will describe the background to the adoption of systems for the proper disposal and recycling of E-waste in Japan, South Korea, China and Taiwan. Although we can observe differences in the timing, design and scope of each nation's E-waste recycling systems due to their respective stages of economic development, industrial structures and existing waste related policy schemes, we can also identify several common factors in the lead-up to their adoption.

The following four domestic factors can be identified in the lead-up to each nation's adoption of a E-waste recycling system: (1) recognition of the difficulty in disposal of E-waste compared to other kinds of waste; (2) the dire state of landfill shortages and environmental impact (including soil and groundwater contamination) arising from increased E-waste volume; (3) growing interest in the recovery and effective utilization of valuable resources contained in E-waste; (4) willingness to develop recycling companies as a "venous industry".

In addition, the process of formulating national policies on E-waste recycling was significantly affected, both directly and indirectly, not just by domestic factors but also by the policies of international organizations like OECD and the EU. Particular examples of factors having a major direct bearing on the formation of E-waste recycling policies include the following: the OECD's Extended Producer Responsibility: A Guidance Manual for Governments' (2001), and the EU's WEEE Directive (2002), RoHS Directive (2002), and REACH Regulation (2006).

Below, we will set aside the common background factors of increased E-waste volume and the accompanying shortage of landfill and environmental impact, and instead focus on examining those background factors in the policymaking process which were inherent to each nation.

In Japan, the Law for Recycling of Specified Home Appliances (Home Appliance Recycling Law) was enacted relatively early in 1991 and covered the recycling of four types of home electric and electronic appliances, namely, televisions, refrigerators, washing machines and air conditioners. Apart from the above-mentioned common factors, the sudden increase in illegal dumping of industrial waste was one of the factors behind the adoption of this law. This increase in dumping led to the amendment of all of Japan's waste policies and the enactment of the Basic Act on Establishing a Sound Material-Cycle Society in 2000, as well as the Home Appliance Recycling Law. In addition, Japan's Home Appliance Recycling Law stipulated a "manifest system", which is defined as a set of forms, reports, and procedures designed to seamlessly track waste from the time it leaves the generator facility where it was produced, until it reaches the off-site waste management facility, not seen in the corresponding laws of the other three nations. This system was introduced with the aim of integrating the management of waste processes from waste generation to transport and final disposal, and to clarify the responsibilities of the relevant stakeholders. Despite positive evaluation of the system's contribution to the technological development of Japan's recycling industry, there have also been some negative assessments such as its effect in raising the social costs of disposing and recycling E-waste in Japan [7].

Background factors unique to South Korea include the oligopoly on the home electric and electronic appliance industry held by the nation's three major companies (Samsung, Daewoo and LG) and consumer criticism of improper disposal of E-waste led by environmental NGOs. As a result, companies concerned about their brand image entered into voluntary agreements with the government in which they conceded to greater producer responsibility. According to hearings involving South Korean E-waste recycling companies and citizens' groups, consumer criticism of corporations led by environmental NGOs had a substantial impact on the formation of the country's E-waste recycling system. This information is based on the hearings obtained by us upon visiting the KFEM and the KAEE from 26 February–2 March 2007.

The background factors endemic to China were that E-wastes, in most cases, have a market value and were improperly disposed of in the recycling process. Although China currently does not have any legislation pertaining to the recycling of E-wastes, a look at subjects presently under investigation reveals that measures to address the illegal distribution and disposal account for a significant portion.

This situation has arisen due to the growing number of individuals who collect, repair and sell used home electric and electronic appliances in response to persistently high demand, particularly from farming villages. Residual substances from the disassembly and repair of these E-wastes are discarded as general waste without proper processing to prevent the release of chlorofluorocarbons (CFCs) and so forth, with the resultant environmental impact developing into a major problem [8]. However, the sharp rise in these used goods is occurring not only from within China, but also as a result of burgeoning illegal imports from Japan and South Korea, both recycling and disposal costs of China being very cheaper than those of these two countries. It is therefore essential that legislation within China be accompanied by cooperation with other East Asian nations.

In Taiwan, the management of contamination arising from the improper disposal and illegal dumping of E-wastes has been identified as a major factor [6]. This led to the design of a system which placed the financial burden of proper recycling on producers and provided subsidies to recyclers for proper disposal. As described above, the background to the introduction of proper disposal and recycling systems comprised some common factors as well as some inherent national factors, and was also strongly affected by international policies, particularly those of the OECD and EU already mentioned. Needless to say, factors not discussed in this chapter, such as the existing waste-related systems and industrial structures of each nation, also affected system design to a certain extent.

3. Comparative Analysis of E-Waste Recycling Systems

This section examines the content of Japanese, Korean, Chinese and Taiwanese E-waste recycling systems and compares them in terms of the timing of the introduction, targeted appliances, role of stakeholders, and their expenses and incentives for participation.

3.1. Timing of the Introduction of Recycling Systems and Targeted Appliances

There are major differences in the timing of the introduction, targeted appliances and stakeholder roles of the E-waste recycling systems in Japan, South Korea, China and Taiwan due to the respective stages of economic development, industrial structures and existing waste-related policy schemes. Table 1 summarizes the transitions, targeted appliances and stakeholder-specific roles of each country's E-waste recycling systems.

Japan was the first country to enact a law specifically concerning E-waste, with the Home Appliance Recycling Law which came into force in 1998. South Korea introduced regulations on E-waste with the adoption of the Waste Deposit-Refund System in 1992 based on the Law for Promotion of Resource Saving and Reutilization (LRSR). Under this Deposit-Refund system, manufacturers of recyclable products, materials and containers are required to pay a deposit for the cost of waste recovery and processing, which is subsequently refunded once the waste has been properly collected and processed. However, this system did not distinguish E-wastes from other types of waste, such as containers and packaging. The system was reviewed in 2003, leading to the adoption of the EPR System which imposed mandatory recycling rates on 21 products including home electric and electronic appliances, containers/packaging, tires and batteries. However, this scheme also failed to distinguish E-wastes from other types of waste. From 2008, the mandatory recycling of E-wastes as well as waste vehicles was separated from the EPR System and stipulated under the Act for Resource Recycling of Home Electric Appliances and Vehicles (Figure 1).

In Taiwan, the Recycling Fund Management Board (RFMB) was initiated in 1998, and placed concern more on the securing of valuable resources in the selection of appliances to be recycled. In contrast, China is still in the process of introducing an E-waste recycling system and legislation is expected in the near future. China is presently considering the inclusion of home electric and electronic appliances and personal computers but, if it maintains its emphasis on resource procurement, then the scope of targeted products covered by law will more than likely be expanded.

Since the adoption of E-waste recycling systems in Japan and Taiwan, there have been discussions of legal amendments but no major reforms have been undertaken to date. South Korea, on the other hand, has undertaken two extensive reforms of its system partly in response to the OECD's EPR Guidance Manual and EU policies, including the aforementioned enactment of a law targeting electric and electronic equipment and vehicles in 2008. In China, the bulk of E-wastes flowing from urban to rural areas are used goods with market value and are therefore rarely perceived as waste, while the valuable substances derived from the repair and disposal of these appliances are seldom recognized for their harmful impact on the environment and on humans. This is the reason why systems such as the "Law on the Quarantine, Inspection and Management of Imported Used Electrical and Mechanical Products" (2003) and China's version of RoHS (2007) have been implemented in advance of systems concerning the recycling of E-waste.

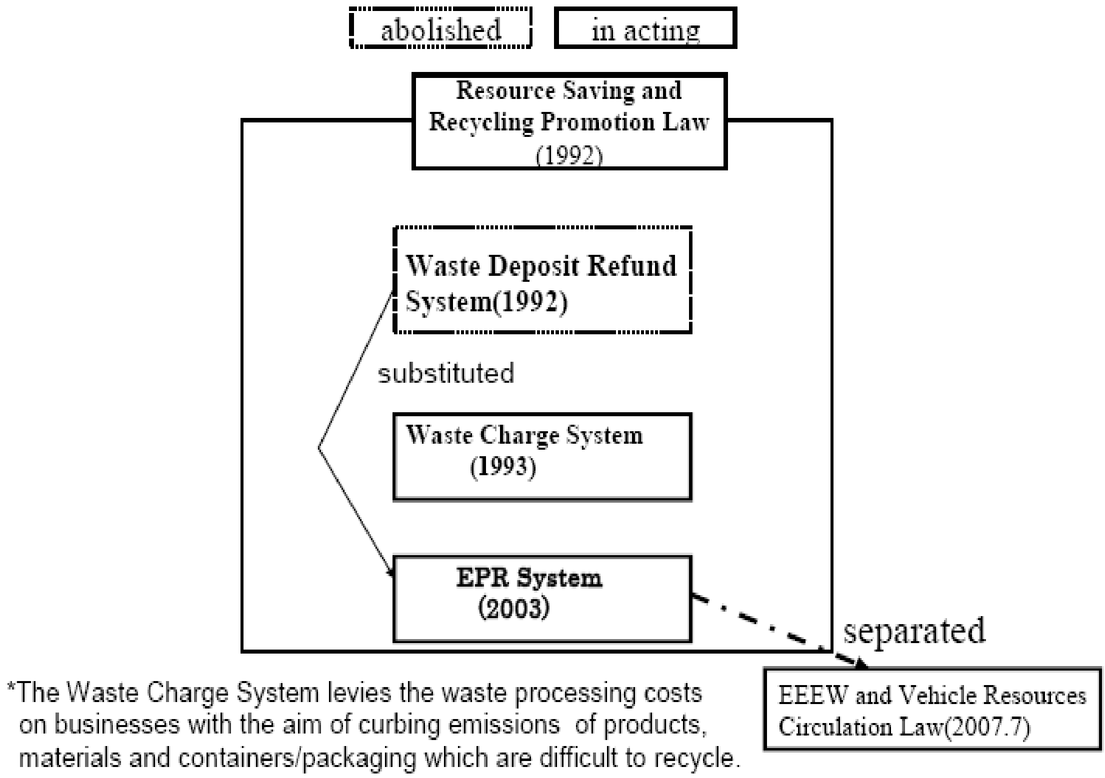
In terms of targeted appliances, Japan clearly specified a standard for selecting the target when enacting the Home Appliance Recycling Law. The product categories targeted by Japan's Home Appliance Recycling Law are required to meet the following conditions: (1) products which are difficult for local governments to recycle; (2) products containing significant quantities of recyclable resources such as metals which are inexpensive to recycle; (3) products capable of adopting readily recyclable components and materials in the design stage; and (4) products which can be transported by retailers upon replacement purchases. Ueta (1992) [9] also proposes the following four general criteria in order to realize recycling activities: (1) the existence of a substantial volume of waste, (2) the presence of valuable metals in the waste, (3) the availability of waste recycling technologies, and (4) the presence of demand for recycled products.

Table 1. Comparative evaluation of E-waste recycling systems in Japan, South Korea, China and Taiwan.

		Japan	South Korea	China*	Taiwan
Law		Home Appliance Recycling System (1998–)	Waste Deposit-Refund System (1992–2002); Producer Responsibility Recycling System (2003–2007); Act for Resource Recycling of E-waste and Vehicles (2008–)	Law on Waste Household Electrical Device Collection, Utilization and Management (under review)	Recycling Fund Management Board (RFMB; 1998–)
Targeted products		TVs, refrigerators, washing machines, air conditioners	Washing machines, TVs, air conditioners, refrigerators, PCs, audio, mobile phones, printers, copiers, faxes	TVs, refrigerators, washing machines, air conditioners, PCs	TVs, refrigerators, washing machines, air conditioners, laptop computers, motherboards, monitors printers
Role of Stake-holders	**Consumers**	Mandatory cooperation on collection ⇒ Retailers (upon replacement purchase), local government, collection companies	Cooperation on collection ⇒ Retailers (upon replacement purchase), local government, collection companies	Cooperation on collection via retailer, local government and collection contractor channels	In many cases, E-wastes are sold for profit
	Local governments	Collect E-wastes from consumer and transport to designated exchange; also collect illegally dumped appliances	Collect E-wastes from consumer and transport to designated exchange; also collect illegally dumped appliances	Collection and transport to storage yards	Management of waste collection centers and recycling consignment/sale to intermediate sellers; management of recyclers and used goods
	Producers	Mandatory collection via retailers; setup of designated exchange	Achievement of mandatory collection/recycling targets; construction of collection centers and recycling plants	No physical obligation	Active collection by major firms but other firms unknown
	Recyclers	Recycling by producer-designated contractors	Recycling via producer consignment	Voluntary collection from storage yards and recycling	Few contractors perform proper recycling
	Collection companies	Voluntary collection; distribution as used goods/parts (including exporting)	Voluntary collection; distribution (including exporting) as used goods (including parts); processing of remnants/residue unclear	Voluntary collection from storage yards and recycling	Private collection channels also exist; status of collection companies unclear

*The roles in China are summarized as they presently stand because the law is not yet enacted.

Figure 1. Transition of cycle related policy in Korea.



As described above, Japan's system stipulates various product selection criteria. However, examination of the product categories targeted by each country's system indicates that the Japanese system clearly recognizes the difficulty of processing E-wastes. Meanwhile, China and Taiwan's selection criteria place greater emphasis on the proper disposal of harmful waste and on obtaining valuable resources. As an example of Japan's approach, current discussions on reforming the E-waste Recycling Law suggest that flat-screen televisions and dryers are likely to be added to the list of targeted products, whereas appliances such as microwaves have been overlooked due to the potential difficulty of collecting them and recovering the associated costs from the consumer. As mentioned above, if China maintains its emphasis on securing resources, the scope of targeted products will probably be expanded.

3.2. Cost Sharing by Stakeholders and Their Incentives

This section compares the physical role and cost sharing for collecting and recycling for different stakeholders and analyzes their incentives for participation.

First, we will analyze the specific roles of each stakeholder in the collection, with an emphasis on physical responsibilities. The responsibilities of consumers, local governments and collection companies arise mainly within the collection process. In Japan and South Korea, the consumer's responsibility lies in cooperating with the other stakeholders (retailers, local governments) during collection whereas in Taiwan, the consumer's responsibility is not clearly stipulated but rather left to the market's discretion. In China, consumers typically sell their E-waste as used goods at present, and their responsibility in terms of collection for final disposal or recycling is expected to be limited.

In Japan and South Korea, the role of local governments is to collect E-waste (*i.e.*, those not subject to replacement purchase) from the consumer and transport them to collection centers operated by the producer. Local governments in Taiwan also collect some E-wastes and transport them to temporary storage yards, although they are not obligated to do so. In addition, local governments in Japan and South Korea are required to collect illegally dumped waste. Illegal dumping is on the decline and is not a major social issue in South Korea, where it is monitored by citizens groups commonly referred to as "*ssu-parazzi*" (a term coined from the Korean word "*ssu*" meaning "rubbish" and the Italian word "*paparazzi*"). South Korea has introduced a system which pays monetary rewards to citizens for reporting cases of illegal dumping to the authorities. However, the collection of illegally dumped waste is one of the main roles of local governments in Japan. Local governments in China are responsible for managing collection centers and overseeing the collection system, and also play a major role in managing used products.

In other words, Chinese local governments are obligated to manage and supervise the collection of E-wastes to a greater extent than the actual task of collection. In Japan, the role of the producer in the collection process is to set up and manage collection centers to temporarily store recovered appliances.

In South Korea, producers are also obligated to meet volume-based recycling targets (herein "mandatory recycling targets") imposed by the government (revised annually). As a result, producers in this country use campaigns and collection contractors in order to meet their recycling targets. In Taiwan, producers have virtually no role in the collection process, and collection itself is not obligatory. As described below, Taiwanese producers only have a financial obligation to pay the cost of recycling to the RFMB. In China, some companies have assumed the task of collection on a voluntary basis, but the volume is very limited.

Next, the cost incurred in the recycling process can be broadly divided into collection cost and recycling cost. Table 2 summarizes the expense of different stakeholders in Japan, China, Korea and Taiwan.

Table 2. Cost Burdens of Stakeholders in Japan, South Korea, China, and Taiwan.

Stakeholder	**Japan**		**South Korea**		**China**		**Taiwan**	
	Collection cost	Recycling cost	Collection cost	Recycling cost	Collection cost	Recycling cost	Collection cost	Recycling cost
Consumer	Total cost	Partial cost	Almost not	Almost not	Almost not	Almost not	Almost not	Almost not
Local government	Illegal dumping collection cost	Almost not	Illegal dumping collection cost	Almost not	Unclear	Almost not	Illegal dumping collection cost	Almost not
Producer	Mainly physical obligation	Mainly physical obligation	Total cost (financial and physical obligation)	Total cost (financial and physical obligation)	Almost not	Almost not	Financial obligation	Financial obligation

In Japan, collection and recycling costs have changed since the E-waste recycling system was implemented, but the consumer cost burden has remained fixed, making it difficult to clearly distinguish which stakeholder is responsible for these costs. However, the cost-burden structure arguably places the financial obligation of recycling on the consumer, and the physical obligation of establishing and operating recycling plants and collection centers on the producer. Japan's local governments are obligated to collect E-wastes at the consumer's request, but the cost of collection is levied on the consumer. The collection of illegally dumped waste, on the other hand, involves both physical and financial responsibilities, with the local government bearing the financial costs.

In South Korea, both the collection costs and recycling costs are generally borne by the producer. However, when local governments collect E-wastes, the consumers are required to pay the collection costs. In Taiwan, producers incur recycling and collection costs to the RFMB upon product shipping, thus producers are at least financially obligated for the volume of E-wastes collected via the RFMB. The fees paid by Taiwanese producers to the RFMB also include management costs and therefore in reality, the costs of both collection and recycling are both borne by the producer. E-wastes not collected through RFMB channels, however, are instead reclaimed voluntarily by collection companies according to market principles, with the collection costs also being borne by these companies.

For recycling costs, Japan's recycling fees are essentially calculated according to "primary transport" (*i.e.*, from consumer to retailer), "secondary transport" (from retailer to factory), and processing and recycling costs. As such, the cost of recycling is generally incurred by the consumer. In Japan, the recycling fee levied on consumers when disposing of Home electric appliances is 1,785 Japanese Yen per cathode-ray tube TV, 2,835 Japanese Yen per LCD and plasma TV, 3,780 Japanese Yen per small refrigerator, 4,830 Japanese Yen per large refrigerators, 2,025 Japanese Yen per washing machine and 2,625 Japanese Yen per air conditioner. Furthermore, collection and transport fees of 1,000 Japanese Yen or more per lot are also levied in some areas. However, fees may be borne by distributors or retailers from the perspective of system operation [10].

By contrast, South Korea's consumers do not have to pay any costs whatsoever for discarding home electric appliances when purchasing a replacement product. In South Korea, both the physical and financial obligations for recycling are borne by the producer, thus, all expenses relating to recycling are incurred by the producer. Taiwan, on the other hand, does not impose the physical obligation for recycling on the producer. Instead, the RFMB on the behalf of producers pays the cost of recycling to a contractor which satisfies the RFMB-designated standard recycling rate, which means that the costs of recycling not conducted through the RFMB are not borne by the producer.

In the preceding paragraphs, we have examined the collection and recycling cost structures in Japan, South Korea and Taiwan. Now, we will examine the incentives that these cost structures provide to each stakeholder in terms of collection volume, illegal dumping and development of recycling technologies. In South Korea where producers incur collection costs, there is an incentive for producers to reduce their collection volume as much as possible. For example, the incentive for negative behavior exists for collecting E-wastes, other than those generated by replacement purchases, so collection volume is largely dependent on sales resulting from replacement demand. For these reasons, South Korea sets recycling targets for producers by stipulating the above-mentioned annual mandatory recycling targets for each product (Table 3). This approach arguably facilitates the steady growth of E-waste collection volumes in South Korea. The annual collection volume of discarded home appliances in South Korea rose sharply between 2004 (the year after adoption of the EPR system) and 2007: from 67,433 tons to 106,376 tons [11,12]. The system also provides producers with the incentive to collect E-wastes, with producers conducting collection campaigns and reclaiming appliances flowing from consumers to the used goods market in order to meet their mandatory collection targets.

Meanwhile, Japan's E-waste collection volume has also grown but the concurrent major increase in invisible flows (*i.e.*, E-waste arising from the used good market and illegal dumping channels) has become problematic. This issue has arisen because Japan's Home Appliance Recycling Law has compelled consumers to bear the cost of collection, thus creating an incentive for consumers either to have their appliances reclaimed by collection companies or dispose of them illegally. In addition, the lack of a physical collection obligation on the part of producers means that there is no incentive for them to increase their collection volume beyond those appliances collected in response to replacement demand or by local governments. Put simply, Japan's recycling law arguably does not provide any incentives for producers to increase collection volumes of their own accord. There is, however, an incentive for producers to increase their collection volumes in order to boost the operating rates of their E-waste recycling plants. If the used goods or export markets were to become active, the law could conceivably have the unintended effect of encouraging the invisible flow of some appliances collected by retailers.

Table 3. Recycling Obligation Rate * of E-waste by Korean Government.

	2003	**2004**	**2005**	**2006**	**2008**	**2012 (target)**
TV	11.6	9.2	11.8	12.6	14.5	21.0
Refrigerator	9.0	10.8	14.1	16.9	18.9	25.0
Washing Machine	25.3	21.8	21.2	23.4	25.3	30.0
Air Conditioner	0.7	0.7	3.6	1.7	2.1	2.6
Personal computer	-	-	8.5	9.4	10.3	14.0
Mobile Phone	-	-	11.9	15.4	18	25.0
Printer, Facsimile	-	-	-	8.4	11.2,11.4	15.0
Copier	-	-	-	9.0	12.7	15.0

* Recycling Obligation Rate (%) = Recycling Obligation Amount/Shipping Amount.

In Taiwan, collection is largely dependent on collection contractors rather than producers or local governments. The higher the subsidies these contractors receive from the RFMB, the greater the incentive to boost their E-waste collection volumes. In contrast, setting the subsidy low will encourage contractors to increase their supply of E-wastes to used goods and export markets instead of dealing with the RFMB. The critical factor in determining collection volumes in Taiwan is therefore subsidies.

Finally, we will examine the incentives that the stakeholder cost burdens provide in terms of developing recycling technologies. In Japan and South Korea, the physical responsibility of recycling is, at the very least, borne by producers. We can therefore reasonably assume that there is an incentive for producers to develop recycling technologies as a way of reducing their recycling costs. Accordingly, the development and streamlining of recycling technologies are advancing in the case of producers operating their own recycling plants. In fact, recycling plants constructed by producers in Japan and South Korea have undergone technological developments (insulation materials, CFC recovery, *etc.*) and improvements in efficiency. On the other hand, where producers outsource recycling operations, there is a need to provide incentives to contractors to develop recycling technologies.

The recycling systems of Japan, South Korea and Taiwan all stipulate standard recycling rates (recycling rates for individual products), although to differing degrees. For example, the recycling rates for televisions, refrigerators, washing machines and air conditioners are 55%, 50%, 50% and 50% in Japan, and 65%, 70%, 80% and 80% in South Korea, respectively. These recycling rates constitute an incentive for producers to provide information and transfer technology to recycling contractors, which in turn enables contractors to develop recycling technologies. In fact, the majority of recycling contractors in South Korea are small to medium-sized operators, thus producers are engaged in providing them with information and support. Meanwhile, recycling contractors in Taiwan are required to possess a certain level of technology in order to participate in the RFMB recycling scheme, and are therefore generally well equipped in terms of technology. In other words, although Taiwan’s producers are the ones responsible for recycling costs, the RFMB’s incentives for the development of recycling technologies are directed more towards contractors than producers.

In summary, the role of consumers and local governments in Japan and South Korea is emphasized in the collection process, while producers play an important role in the recycling process. However, South Korean producers are also required to fulfill a certain role in the collection process due to the imposition of volume-based recycling targets. From the perspective of EPR, South Korean producers therefore have a considerable physical and financial obligation in both the collection and recycling processes, whereas other stakeholders are only required to assume a limited “cooperative” role. In Japan’s case, while responsibility is largely held by local governments, it is now being spread to the producers and in some aspects to consumers who have financial responsibility for the collection and recycling of E-waste.

4. Conclusions: Challenges toward the Sound Circulative Economies in East Asia

In this paper, we have undertaken a comparative analysis of the backgrounds, targeted products, stakeholder-specific roles and cost burden structures of legal systems relating to E-waste recycling in Japan, South Korea, China and Taiwan, touching upon the details and current status of these systems. While the E-waste recycling systems adopted in each country vary to a certain extent, we have demonstrated that they are all moving towards enhancing the onus on producers, largely due to the influence of the EPR principle. A brief outline of each nation's cooperative feasibility is provided below together with a summary of their unresolved issues.

One of the most important issues for Japan is the increasing volume of E-wastes arising from invisible flows. The producers entrust the retailer with the E-waste recycle law, which levies a recycling fee on consumers when disposing of home electric appliances. Retailers have an incentive to cheat the recycling fees by treating the E-wastes to the invisible flow instead of the legal flow. In addition to the export of used goods, the improper disposal and illegal dumping of E-wastes by scrap traders not covered by the Home Appliance Recycling Law have been highlighted as challenges. The underlying causes of these problems include the fact that products subject to recycling in Japan are determined not on the basis of shipped volume but on the actual collected volume, and the fact that collection costs are borne by the consumer.

Despite various arguments regarding the method for calculating South Korea's mandatory recycling targets, the system appears to have caught on among producers in light of the fact that actual recycling levels constantly surpass mandatory collection targets. The actual rate of achievement of the mandatory reutilization rate (2006) was 106% for TVs, 117% for refrigerators, 127% for washing machines and 182% for air conditioners, thus surpassing the mandatory recycling rate in each category. On the other hand, the increasing social costs of imposing the mandatory recycling rates and the setting of the recycling rates themselves have been underscored as major problems in South Korea's system. South Korea's recycling rate differs from that of Japan in that products are counted in the recycled weight provided that they are used as a resource of some kind. It will therefore be necessary to make the recycling rate stricter in the future to encourage producers to develop recycling technologies.

In Taiwan, the collection and recycling of E-wastes under the RFMB system has produced some positive outcomes, but the sheer volume of E-wastes processed outside of this system is a major cause for concern. The only solution for this, under the current system, is to increase substantially the subsidy to collection traders and recycling manufactures, but this would be difficult as it would force producers to bear more of the cost. Therefore, it would be important to revise the system to obligate producers to take physical responsibility while maintaining the current RFMB system.

One problem shared by the systems of Japan, South Korea and Taiwan is that they do not really leverage the benefits of the DfE or DfR approach, one of the key objectives of EPR. In other words, the E-waste recycling systems of these countries do not provide producers with enough incentives to adopt DfE. The reason is that although producers would derive better cost benefits by cooperating in their E-waste collection and recycling costs, disclosing information on component materials, assembly methods and product design poses a dilemma as these are important elements in determining a company's product value. The construction of a framework which incorporates data obtained from the collection and recycling of waste household products into the product design stage is therefore a major challenge towards the creation of better circulative economies [13].

China has yet to establish a system for recycling E-wastes, and thus we have limited our remarks in this study to a summary of the present situation. However, we will now examine the feasibility of China's cooperation in recycling based on its relationship to the other three countries. Japan, South Korea and Taiwan currently do not have substantial domestic used home electric and electronic appliance markets, partly due to the rising income levels in all three nations. However, none of these three countries has any regulations governing the export of used home electric and electronic appliances, thus the export of these goods to China is growing exponentially. This problem is being exacerbated by the rising number of illegal exports in an attempt to dispose of E-wastes. It is clear that this cross-border transfer of E-wastes cannot be resolved by the exporting or importing nation alone, and international cooperation is indispensable to finding a solution.

Japanese, South Korean and Taiwanese home appliance manufacturers have made inroads in China, thus any E-waste recycling system to be enacted in China will inevitably include products from these three countries. This suggests that the likelihood of China cooperating is relatively high. Therefore, in order to resolve the cross-border transfer of E-wastes it will be necessary to conclude a regional producer agreement involving the major producers in the region, and to actively undertake the creation of a system to monitor and track the cross-border transfer of E-wastes as well as the international division of recycling operations, while also examining systematic reforms to enable each country's system to deal with this issue.

Acknowledgements

This study was done as a part of Japanese Grant-in-Aid for Scientific Research.

References

1. Na, S. Analysis of E-waste Recycling Systems in East Asia. In *Environmental Charge Systems in East Asia: Features and Challenges*; Lee, S., Ed.; Showado: Kyoto, Japan, 2010; pp. 214-227.
2. Kojima, M. *Recycled Resource Trading in Asia*; Institute of Developing Economies: Tokyo, Japan, 2005.
3. Terazono, A.; Murakami, S.; Yoshida, A.; Murakami (Suzuki), R. Analysis of material cycle systems for E-waste and waste plastics in Asia. In *2006 Scientific Research Report on Waste Processing*; National Institute for Environmental Studies: Ibaraki, Japan, 2007; pp. 72-84.
4. Togawa, K.; Murakami, R. A Comparison of Home Appliances and Automobiles Recycling System in Japan, Korea and Taiwan. *Mita J. Econ.* **2001**, *94*, 23-47.
5. Murakami, R. *Waste Policies in Japan, Taiwan and South Korea Focusing on the Processing and Recycling of Used Home Electric Appliances*; Ph.D. Thesis; Graduate School of Social and Cultural Studies, Kyushu University: Hukuoka, Japan, 2005.
6. Murakami, R.; Chung S.; Kojima M. A Comparative Study of E-waste Recycling Systems in Japan, South Korea and Taiwan from the EPR Perspective: Implications for Developing Countries. In *Recycling in Asia*; Kojima, M., Ed.; Institute of Developing Economies: Kyoto, Japan, 2008; pp. 299-345.
7. Yoshida, F. Comparison of E-waste Recycling in Japan and Europe. In *Society for Environmental Economics and Policy Studies 2008 Essay Abstracts*; The Society for Environmental Economics and Policy Studies: Osaka city, Japan, 2008; pp. 63-64.
8. Tong, S; Park, S. Characteristics and Issues of China's EPR System—Case Study of E-waste. In *Environmental Charge Systems in East Asia: Features and Challenges*; Lee, S., Ed.; Showado: Kyoto, Japan, 2010; pp. 257-292.
9. Ueta, K. *Economics of Waste and Recycling*; Yukihaku Publishing: Tokyo, Japan, 1995.
10. Hosokawa, E. *Resource Recycling Societies—System Design and Policy Prospects*; Keio University Press: Tokyo, Japan, 2008; pp. 63-97.
11. *Survey on E-waste Collection and Reutilization*; Korea Association of Electronics Environment: Seoul, Korea, 2009.
12. *EPR Information System*; Korea Association of Electronics Environment: Seoul, Korea, 2010.

13. Lee, S. Extended Producer Responsibility System in Korea—Case Study on Recycle Incentive System of E-waste Recycling in Korea. *Meijo Rev.* 2006, *10*, 61-91.

A Comparison Study of Economic Instruments for WEEE Recycling Between Two Chinese Societies, Taiwan and China

Chun-hsu Lin* and Lihchyi Wen

Energy and Environmental Research Center, Chung-Hua Institution for Economic Research
75 Changhsing Street, Taipei, Taiwan 106
** chlin@cier.edu.tw*

Abstract

Starting January 2011, the potentially largest home appliance market in the world, China, will adopt the Extended Producer Responsibility (EPR) for its increasingly serious waste problem. For the unique social and economic conditions like China, the EPR system should be different from those implemented in developed countries. Therefore, from the similar cultural perspective, our goal in this paper is to propose a model of EPR that can suit the complicated situation in China. In another Chinese society, Taiwan's Environmental Protection Administration (Taiwan EPA) has been in charge of the recycling duty for 14 categories of domestic Due-Recycled waste in Taiwan Since 1998, including home appliances and information technology (IT) products. The national recycling scheme, also an EPR system is working by collecting the collection-disposal-treatment fees, or "recycling fees," from producers to subsidize the registered recyclers for their recycling efforts. In the past eleven years, the performance of collection and treatment has been concerned by many parties including Taiwan EPA itself. We also examined the environmental performance of the recycling fee system for Waste Electrical and Electronic Equipment (WEEE). Based on intensive interviews and discussion with major producers in Taiwan in 2008, this paper thus proposes an ideal model for Taiwan's WEEE recycling system, a Private Recycling Organization (PRO) including the statute of the system, the material flows, the monetary flows, the auditing and reporting mechanism, and, the environmental performance standards. Hopefully this model can also be applicable to China.

Since the EPR systems have been an internationally recognized concept for a nation's recycling policy, the more critical issue of the EPR systems would be how to optimize the environmental at a well-operated financial scheme. In both Chinese societies, especially in China, we suggest the responsibility of producers should be more enhanced to allow more flexibility achieving a better environmental status. On the other hand, the new challenge for the PRO in Taiwan will be the integration of the new system with the currently existing national recycling system. If the new challenge is overcome, the transition from a well-established system to the new system can be easily achieved. Besides, the intention of producers is also a key factor especially under the circumstance of global financial crisis that has made producers more conservative to adopt a new system. On the other hand, the stance of the government is also crucial to the success of the PROs.

Keywords: Due-Recycled waste, recycling fund, collection-disposal-treatment fee

1. INTRODUCTION

By the "Regulation for the Management of the Recycling and Disposal of Waste Electrical and Electronic Products" (so-called China WEEE) on March 4, 2009 China promulgated the system of Extended Producer Responsibility for its WEEE recycling and will put it into force on January 1st, 2011. Although environmental regulations in China were more recently developed, a sound environmental management system is in fact more crucial to the global environment since China, a country with more population than any others, has become a manufactory factory for the world. It is worthy of caution and further study to understand the impact of its WEEE recycling system and, if possible, suggest a more feasible and efficient operation model.

On the other side of the Taiwan Strait, resource recovery in Taiwan was undertaken by individuals and small size enterprises long before the government intervened with rules and regulations. Since recycling of PET bottles became law in 1987 by administrative order, the market entered a new era. However, it has been a long and difficult road. In 1998, recycling business in this country changed from an entirely privatized enterprise to the current state corporation [1]. The role of government changed from setting the rules, to supervising the work performed under these rules, to taking full responsibility for the work. On the other hand, except for paying fees, the responsible industries are almost exempt from any obligation or responsibility to collect, dispose of, and treat these products they manufactured or imported. From another perspective, the Extended Producer Responsibility (EPR) system in Taiwan means producers only take the "financial responsibility" and the Recycling Fund Management Board (RFMB) of Taiwan EPA takes the "physical responsibility" [2].

With a similar cultural background, Taiwan's model should be able to provide a good reference in the process of constructing a well-functioning system in China. In fact, the principles of the planned system model in China are also similar to those under operation in Taiwan. However, the society of China is much more complicated than Taiwan. Whether the Chinese system can be more guidance-oriented instead of involving government involved in every aspect of the system operation is a issue of concern in this paper.

2. CURRENT STATUS OF WEEE LEGISLATION IN CHINA

The main components of China WEEE include the regulations in four aspects:

1. A list of due-recycled wastes (Article 3)

As in China WEEE proposed a priority list of waste products for recycling, China at the first step will start requiring five electric and electronic wastes due for recycling from January, 2011 including air conditioners, refrigerators, CRT TV sets, washing machines and desktop computers. The list is proposed based on four considerations of the waste products: environmental risks, waste generations, economical feasibility and administrative feasibility of take-back.

2. A treatment plant certification system (Article 6)

The treatment plants, disassembling factories and regenerated material using facilities should get national certification before processing any take-back WEEE. The certification system is designed to achieve a certain degree of recycling performance by recycling processing related parties.

3. Recycling fund (Article 7)

The producers of electrical and electronic equipments should submit recycling fees which become recycling fund. The recycling fund is then used as the subsidy to the certified recycling parties for their recycling operation cost compensation.

4. Promotion of recycling business (Article 21)

The government should be in charge of guiding the promotion of recycling operation through three mechanisms: establishing recycling performance indicators, enhancing regional infrastructure, establishing recycling business clusters. It is estimated 90 treatment plants will be needed across China with the treatment capacity of 10,000 tons per year per for each plant. The environmental protection authorities at the provincial level should be in charge of the monitoring and auditing on these treatment plants.

3. CURRENT STATUS IN TAIWAN

In the past decade, the RFMB has been most criticized for its operational cost. Also, the producers or responsible industries do not really take the responsibility of take-back and recycling but paying collection-disposal-treatment fees only. Collection and treatment agents are asking for higher subsidy from the RFMB regardless of their spare operating capacity. Currently there are thirteen WEEE recyclers around the country (Fig. 2). Therefore, reforming the operation of the national recycling system should be undertaken. While more and more volume and variety of waste electrical and electronic equipment are emerging in the future, the producers should take more responsibility operating the recycling schemes and start from the non-Due-Recycled WEEE. Besides, the competition mechanism among collection and treatment agents should also be introduced to future recycling systems to improve the efficiency of operation.

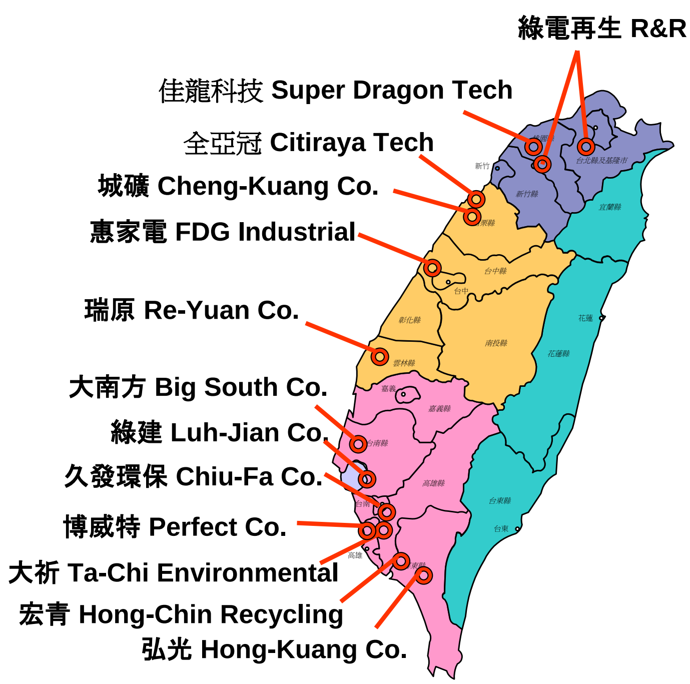


Fig. 1. Distribution of WEEE treatment plants in Taiwan

4. PROBLEMS AND COMPARISON

In the past decade, through the mechanisms of recycling fee system, the RFMB system in Taiwan has successfully set up the operation of recycling and achieved its performance to a certain level. The issues of concern primarily belong to the cost and the efficiency of operation.

The cost of operation is somewhat higher than it should be for two reasons. First, any recycler can register as the subsidy-receiving entity from the Taiwan EPA as long as they can provide sufficient environmental protection performance, which has resulted in over-capacity for recycling treatment and low efficiency of treatment in each recycler. Secondly, due to the different characteristics of recyclers, it is difficult to estimate the real average cost of operation that is used as the basis to determine recycling fees and subsidy levels.

The lack of efficiency comes from intense governmental involvement in the system operation, most importantly, the fee rates of recycling fees and subsidy. Since the fund from recycling fees is in fact the driver for the whole system, it is extremely important to determine the appropriate levels of the recycling fees. However, it is difficult for the government machine to have the sense of market and the flexibility in adjusting the fee rates at the proper timing and proper pace.

Although Taiwan and China are both Chinese societies, fundamental differences exist in every socio-economic aspect. In addition, the future China system is 90% similar to Taiwan's current system and the socio-economic condition is much complicated than Taiwan The problems in the current Taiwan system would also happen more wore in China if no proper controlling mechanisms set up.

5. A PROPOSED MODEL OF PRIVATE RECYCLING ORGANIZATION

Nevertheless, there is room for improvement and discussion for better performance. One of the issues concerned is the function and operating structure of the RFMB. At the same time, in order to further promote the WEEE recycling in Taiwan, Taiwan EPA is scheduled to declare all of WEEE products as Due-Recycled waste in the near future, meaning the mandatory take-back and recycling regulations will be imposed on all electrical and electronic equipment in addition to current take-back items [3]. For future Due-Recycled electrical and electronic equipment, however, the operation schemes for these items are not necessary to be the same as current RFMB system. Based on the principle of the Extended Producer Responsibility, we suggest a conceptual structure of recycling platform that should be operated by responsible industries, or producers, not by the government. Industries should operate a recycling platform on their own for the future Due-Recycled wastes.

The private schemes have to cooperate but not compete with the RFMB system. For example, the wastes taken back by the private systems should be the items currently excluded from the Due-Recycled list. We suggest the model of operation for future private schemes. In which, the RFMB is in charge of the producers' registration and reporting but not subsidize the treatment agents. Instead, the private platform chooses the most favorable treatment agents based on their own interests and directly contracts with the treatment agents as Figure 2.

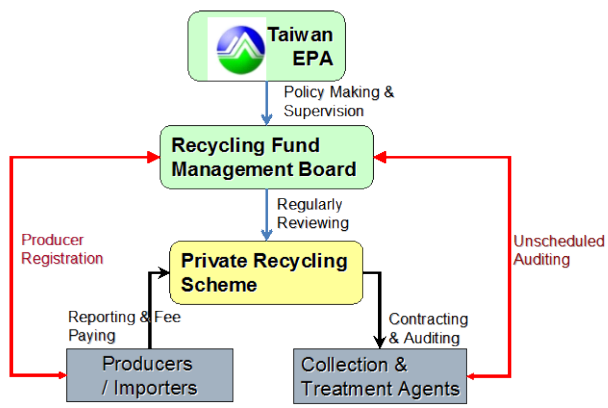


Fig. 2. Recycling Scheme for future Due-Recycled WEEE

Although the model for a private recycling scheme can be in different formats than the structure presented, the principles will be similar including producers take the obligation of running the platform scheme and select treatment agents or facilities from their standing point to maximize the system efficiency.

6. PRINCIPLES OF PRO OPERATION

In the beginning of our study, we collected and analyzed various data about the current and future status of WEEE recycling in Taiwan. International case study on private recycling schemes was also conducted for references. In order to prepare the establishment of a private recycling organization (PRO) for WEEE, the first public hearing for producers was held on July 16, 2008. A committee composed by the representatives of related parties was established on August 8, 2008. By September 26, 2008, we organized nine workshops for the committee to discuss the formation principles of the producers' recycling scheme. Based on the conclusions from those workshops, the primary proposal for the producers' recycling scheme has been completed and then released to the public on December 25, 2008.

More specifically, ten representatives of the committee are from Taiwan EPA, academic researchers and producers in information technology industry including Hewlett-Packard, ASUS, DELL, Acer, EPSON, Lemel, Chimei, Nokia, ViewSonic and Taipei Computer Association. Meeting once a week for two months, the committee members continuously participated in a series of workshops and come out a proposal of a future PRO. The issues discussed include the organizing structure of the PRO, the channels of WEEE collection, items to be collected, members' obligations, partnership with recyclers, financial management, environmental performance indicators and legal issues. After the ten workshop meetings by the PRO committee, several principles of operation have been clarified. The roles of government and producers should be shifted to the following positions.

The government should:

1. Assist and supervise the operation of PROs.
2. Provide suggestions on the legal framework to regulate members' obligation and rights.
3. Select third parties to audit and certificate the recycling operation of PROs.
4. Encourage the research and development on recycling technology as well as best uses of secondary materials produced from recycling.
5. Engage in environmental education and recycling campaign.

On the other hand, the producers should:

1. Operate and manage the PROs on their own.
2. Suggest the annual objectives of collection and collection.
3. Establish the model of financial management including setting up the recycling fees and contract with recyclers.
4. Set up the categories, items and technical standards for collection and recycling

operation.

5. Reduce the operational cost through market mechanisms.
6. Initiate the dialogue between producers and the government for policy making.

The consensus about the aspects of PROs discussed from the committee meetings are as follows.

6.1. Organizing structure

Currently, there are only two levels of the recycling operation, the government and the RFMB of government. In the new model, the whole structure of system would be composed of three levels: the government, a registration platform and the PRO itself as Fig.2. As proposed by the committee, the government, or Taiwan Environmental Protection Administration, should be responsible only for policy making and the supervision of the whole recycling system. The RFMB of Taiwan EPA, with governmental authority, can be only responsible for registration but more importantly the certification and verification. The PRO should take the responsibility of the real operation of take-back and recycling. Under these conditions, the PRO is suggested by the committee to be a non-profit foundation originally funded by producers, instead of in the format of a company.

6.2. Collection channels

Based on the conclusions from the committee workshops, the new PRO should utilize the existing collection channels which include private collectors, public sanitary squads, used goods dealers and retailers (Fig. 3). The waste products to be collected and recycled can be extended to be the products from the non-members of the PRO. Also, the PRO will accept the waste products from contracted collectors only, meaning the collection of WEEE would be a semi-opened system.

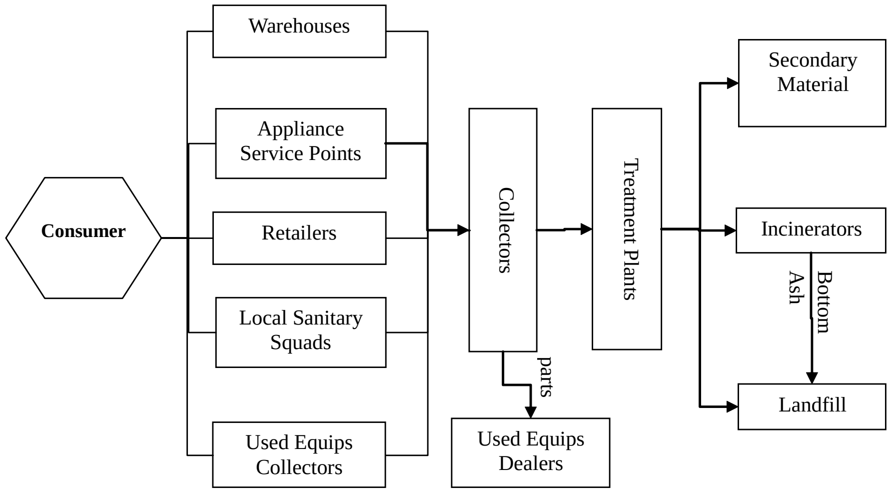


Fig. 3. Channels and destinations of WEEE in Taiwan

6.3. Take-back items

Currently Due-Recycled wastes designated by the RFMB include refrigerators, TV sets, washing machines, air conditioners, printers and personal computers (desktops and laptops) etc. In the future, the coverage of take-back items by the new PRO should be extended to all WEEE items eventually. But at the early stage of the new PRO, the items to be collected should start with the existing take-back items by the RFMB. The collection by the PRO should be ratified as the credit of the members who are also registered as producers under the RFMB

6.4. Membership management

The members of the new PRO should count above 50% of the producers in terms of annual sales in the domestic market. At the beginning, without legal enforcement, the participants of the PRO will be voluntarily based. The participants of the PRO should follow the principles of PRO operation and have the right of waiving the financial obligation to the RFMB to a certain extent.

6.5. Partnership with recyclers

As shown in Fig. 1, there are thirteen recycling treatment plants in Taiwan to process the recycling operation of wastes collected by the RFMB system. But the real operation of each treatment plants is currently far below each recycler's processing capacity. In the future, instead of utilizing all of the existing treatment plants, the PRO can select and contract with the treatment plants based on the waste quantity and locations of the wastes. Through the selection and bidding process, the cost for recycling treatment can be reduced because of the competition among recyclers. Also, the contracts with recyclers have to be regularly renewed, instead of issuing permanent qualification. The selection of recyclers should be based on three criteria:

1. Technology level and past environmental performance.
2. Social welfare and public affair involvement.
3. Recycling capacity and ability.

With a limited number of treatment plants, each plant can also have higher economy scale for better profits.

6.6. Financial management

The producers committee decided to adopt financial responsibility to the PRO instead of individual physically recycling responsibility. Therefore, in the future, the producers have to regularly pay recycling fees to the PRO based on the sales amounts. The rate of recycling fee for each unit of product would be determined by the special committee under the PRO based on the principle of achieving a balanced budget in the future.

Besides, because participation in the PRO is voluntarily based, the producers have to face two options of regulations for recycling, one by the RFMB and the other by the PRO, and then make adjustment between them to get best interests for their own organizations. But the assistance from government, mainly reasonable financial incentives for the producers is important.

6.7. Environmental goals

Collection rates, defined as the amount of collection divided by the amount of waste generation for each type of waste for each year, are currently the main performance indicators used by the RFMB of Taiwan EPA. All parties including the government, environmental groups and academia etc. also in fact concern about collection rates only. The committee for the PRO actually has adopted more indicators for the evaluation on the PRO in the future including recycling rates, annual collection per capita and collection rates. Recycling rates refer to the amount of secondary materials retrieved from the collected wastes divided by the amount of waste treated. Annual collection per capita has the same meaning as EU WEEE requiring its member states to collect 4kg of WEEE per inhabitant [4]. Considering the current achievement by the RFMB, the committee sets the goals for these three indicators are as Table 1.

Table 1. Proposed environmental goals for the PRO

Indicators	**Goals in the test run**	**Goals in after test run**
Annual collection per capita	0.5kg*	To be decided after the test run
Recycling rate	70%**	80%****
Collection rates	55%***	To be decided after the test run

* For IT products only and excluding the collection by the RFMB, 1.1kg

** Current recycling rate is 86% for IT products by the RFMB

*** Current collection rate is 54% for WEEE products by the RFMB

**** 85% as the goal for 2015 for the EU WEEE directive

6.8. Administrative and legal issues

Since the current RFMB recycling system has been operating for more than ten years, the new PRO should be first integrated with the current system instead of replacing the current system. However, the obligation of the producers who participate in the PRO should be regulated or protected. Therefore, the government, or Taiwan EPA, should provide assistance to the producers suggested by the conclusions of the committee.

For the short term, assistance more at the administrative level can be provided as follows.

1. Taiwan EPA should sign an administrative contract with the PRO and allow the PRO to engage in recycling operation.
2. Taiwan EPA should waive the exiting obligation of the producers to pay recycling fees and the sales amount to the RFMB in the test run period.

3. Taiwan EPA should encourage the participants in the test run period of the PRO by the follows:
   - The recycling credits in the test run period can be part of future obligation fulfillment.
   - The recycling performance in the test run period can become the referenced recycling objectives of the PRO.
   - The RFMB should financially support the operation of the PRO as the

In the long run, the legislative issues also have to be considered as follows.

1. Taiwan EPA should modify the Waste Disposal Act to ensure the legal status of PROs.
2. Taiwan EPA should restrict the take-back items to be handled only by the contracted collectors and recyclers.
3. Taiwan EPA should set up collection points at public locations.
4. Taiwan EPA should establish Environmental Information Disclosure Act to ask recyclers release environmental information to the general public.

7. CONCLUSIONS

Since the EPR systems have been an internationally common concept in recycling policy, the more critical issue of the EPR systems would be how to optimize the environmental at a well operating financial scheme. Especially, the problems from Taiwan experiences can be concluded as follows.

1. Lack of information for of recycling fee and subsidy setting
2. Excess profits for recycling enterprises
3. Recycling enterprises collude, fix the price for collectors, and evenly distribute the recycling amounts
4. Collected recycling enterprises work together to lobby the government for its own benefits

The situations in Taiwan as mentioned above would result in a imperfect market and great social losses. In a developing country like China, the EPR system used in Taiwan is a good reference since it is a simpler system for producers to take part in. However it is difficult to have the government-involved system smoothly going in China with heterogeneous socio-economic conditions. We therefore suggest PRO systems in both Taiwan and China. The new challenge for the PRO in Taiwan will be the integration with the currently existing national recycling system. Then the transition from a well-established system to the new system can be easily achieved. Besides, the intention of producers is also a key factor especially under the circumstance of global financial crisis making producers more conservative to adopt a new system. On the other hand, the stance of Taiwan EPA is also crucial to the success of the PROs

Acknowledgement

The authors wish to acknowledge the Taiwan Environmental Protection Administration for financial support and administrative assistance on part of this research through Project No.EPA-97-HA13-03-A077.

References

[1] Fan, K.S., C. Lin and T.C. Chang. Management and Performance of Taiwan's Waste Recycling Fund. Journal of Air & Waste Management Association 55:574-582 (2005).

[2] Lin, C-C. and C. Lin. What substances or objects should be recycled? The recycling legislative experience in Taiwan. Journal of Material Cycles and Waste Management 7(1):1-7 (2005).

[3] Wen, L.C. C. Lin and C. Hsu. Planning and Optimization for Producers' Waste Electrical and Electronic Equipment Recycling Schemes. Final report to Taiwan EPA (2009) (in Chinese).

[4] European Parliament and of the Council. Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). (2003)

An Analysis of the Effects of a Waste Tax on Reducing the Final Disposal Amount of Industrial Wastes in Mie Prefecture

YAMASHITA Hidetoshi[♣]

1. Introduction

Theoretically it is suggested that environmental taxes are an effective means of internalizing the external diseconomies arising from environment burdens due to economic activities, and leading them to an appropriate level. Some theoretical research on the application of environmental taxes to wastes are, for household economies, Dinan (1993) and Fullerton and Kinnaman (1995), and regarding businesses, Kohn (1997) and Conrad (1999). Some of the empirical analyses of waste taxes with numerical simulations suing CGE models are Masui et al. (2000, 2001), Washida (2004), and Okushima and Yamashita (2005), which indicate the hoped-for waste reduction effect with a prescribed tax rate. As this shows, there is comparatively much research on the ex ante assessment of policies by means of empirical analyses employing theoretical studies and models, but when it comes to examples of application to actual policies, there are few ex post assessment studies that have quantitatively analyzed effectiveness, being limited, to the author's knowledge, to the few described below.

Japan's Law on Decentralization of Government Power, which entered into force in 2000, made it easier for municipalities to enact non-statutory special-purpose taxes. Municipalities saddled with many policy challenges for industrial waste management began instituting industrial waste taxes using non-statutory special-purpose tax frameworks. Industrial waste taxes (they go by various names depending on the municipality, but this paper will use "industrial waste taxes" as a blanket term for tax levies on industrial wastes) have the two policy objectives of reducing waste generation using the price mechanism, and gaining a financial resource to deal with wastes through tax revenues. As of April 2007, 28 municipalities throughout Japan had instituted them. Institutional design differs from one municipality to another, and they are divided broadly into four types. First, is (a) the business self-assessment and payment system, represented by Mie Prefecture, which was the first to introduce it; and second is (b) the final disposer special collection system, which is used by prefectures in the Chugoku and Tohoku regions. These two systems impose the tax payment obligation on the waste generator (party transporting waste to a disposal site), but theoretically it is suggested that (a), under which the generator must pay tax directly, provides a greater waste reduction incentive. Third is (c) the incinerator/final disposer special collection system instituted by Kyushu prefectures. This improves on (a) and (b) by broadening the taxation target group, and it is suggested that this theoretically provides the greatest incentive. Fourth is (d) the final disposer taxation system, which is used by Kitakyushu City. Its institutional design narrows the focus to securing a financial resource.

It would seem very meaningful to examine whether these differences in institutional design relating to effectiveness of waste reduction incentives have influenced changes in the actual industrial waste final

[♣] Graduate School of Economics, Hitotsubashi University
2-1 Naka, Kunitachi City, Tokyo, 186-8601, Japan, hide@econ.hit-u.ac.jp

disposal amount. As theory suggests, the stronger the incentive that a system provides, the greater its waste reduction effect, but do results bear that out? If results differ from theory, then why? Based on this critical awareness, one can cite the following past research on–ex post assessments of industrial waste taxes. Chugoku Bureau of Economy, Trade and Industry (2006) conducted a questionnaire survey of waste generators and disposal contractors in five Chugoku region prefectures. It reported that 27.5% of the generators said less waste was generated after the tax was instituted. Sasao (2010) conducted a quantitative analysis using panel data from all 47 prefectures to examine, by taxation type, whether instituting industrial waste taxes was effective in reducing the final disposal amount.

This study focused on the industrial waste tax instituted by Mie Prefecture, the first in Japan to do so, and used decomposition analysis to examine change in the final disposal amount of industrial waste generated in the prefecture. Based on analysis results, a brief discussion is conducted on the magnitude of the industrial waste final disposal reduction effect achieved in conjunction with introduction of the industrial waste tax.[1] While the Chugoku Bureau of Economy, Trade and Industry (2006) conducted a micro analysis focusing on individual businesses, and Sasao (2010) performed a nationwide analysis employing macro statistics, this study fits between them.

2. Mie Prefecture's Industrial Waste Policy and Statistics

This analysis compares the change in final disposal amount (an overall decline of 177,400 t) at two points in time, FY2000 and FY2004. The reason for choosing these two times is that they correspond to the years in which Mie Prefecture carried out a "Industrial Waste Fact-Finding Survey," which it performed at regular intervals under the Waste Management Law.

Of particular interest regarding the situation with industrial wastes in Mie Prefecture during this time period was the introduction of its industrial waste tax in FY2002. This law is a non-statutory special-purpose tax to cover the costs of measures associated with reducing the generation of industrial wastes, recycling, volume reduction, and other proper disposal (Industrial Waste Tax Ordinance (below, "Tax Ordinance"), Article 1). Whether in Mie or other prefectures, the ordinance states that businesses which generate industrial waste must pay the tax, and it levies the tax on parties that take industrial wastes to intermediate treatment facilities and final disposal sites in Mie Prefecture (Article 4). The tax base is weight when industrial wastes are taken to final disposal sites, and on weight multiplied by a certain processing coefficient when taken to intermediate treatment facilities. The tax ordinance provides that businesses are exempted from the tax when they take wastes to prefecture-designated recycling facilities (Articles 7 and 8). The tax rate is ¥1,000/t industrial waste (Article 9), and there is a tax exemption limit, by which businesses are exempted from the tax when the annual tax base is under 1,000 t (Article 10).

The "Industrial Waste Fact-Finding Survey" used in this analysis should not be understood to actually measure the industrial waste flow because it makes estimates using the activity level of the entire population (for the manufacturing industry this is, for example, monetary amount of manufactured

[1] This paper is based on the results of research conducted with support from Hitotsubashi University FY2007 Financial Support for Individual Research, and a Ministry of Education, Culture, Sports, Science and Technology Grant-in-Aid for Scientific Research, Young Researchers (B)20700036 "An analysis of the effects of the waste tax on the reduction of the final disposal of industrial wastes" (research representative, YAMASHITA Hidetoshi).

products shipped) based on questionnaires mailed to affected businesses. In FY2004 the valid questionnaire response rate was 30.5%, and the activity level coverage rates (the percentage of the overall population activity level represented by the total activity level of the responses) were 39.4% for the construction industry and 77.9% for manufacturing. As this shows, the "Industrial Waste Fact-Finding Survey" data have errors introduced at two stages: when individual businesses response to questionnaires, and when retrieving questionnaires and estimating population values. Therefore one must bear in mind the possibility for discrepancies with the true situation.

Additionally, "Industrial Waste Fact-Finding Survey" covers industrial wastes generated in Mie Prefecture, and therefore includes statistics on intermediate treatment and final disposal both in Mie and other prefectures. Accordingly, final disposal amount includes wastes taken to final disposal sites in other prefectures. On the other hand, because industrial wastes generated outside Mie are not covered by the survey, amounts brought to intermediate treatment facilities and final disposal sites in Mie from other prefectures are not included. In this respect, one must note the disparity with statistics for industrial waste taxes levied on the amount of waste brought to facilities in Mie.

3. Decomposition Analysis Overview

Our decomposition analysis follows that of Yamashita and Yokemoto (2004). According to Hoekstra (2005), decomposition analysis could be seen as a comparative statics method for understanding the effects of determinants that influence the expansion of a certain variable. A decomposition analysis that use Input-Output model in particular is called a structural decomposition analysis (SDA). An analysis which uses industry sector-level or national-level data is sometimes called an index decomposition analysis (IDA). On the theoretical aspects of decomposition analysis, readers should refer to Fujikawa (1999) and Hoekstra (2005).

Mie Prefecture's industrial waste statistics record the amounts of relevant industrial wastes by industry type and by waste type at each stage of the management flow from generation to final disposal. This analysis determines the industrial waste flow at four of those stages: "generated amount," "discharged amount," "transported amount," and "final disposal amount." These are related as shown below.

Generated amount = discharged amount + recyclables amount
Discharged amount = transported amount + amount of self-reduced volume + self-recycled amount
Transported amount = final self-disposal amount + outsourced-treatment amount
+ stored amount and other
Final disposal amount = final self-disposal amount + final disposal amount after outsourced treatment

This analysis gives the following categorization to the options that could be factors behind a decrease in final disposal amount. First, even when there is no intent to reduce industrial waste, the total amount of waste discharged will decrease if a company's production level declines owing to a business downturn. This "production level decline owing to a business downturn" is Factor (1). Next, there are instances in which actions are taken with the intent of reducing industrial waste. A principle is that those who discharge industrial waste are responsible for its treatment. Thus with regard to a decrease in final disposal amount as well, decision-making about industrial waste treatment by discharging businesses is a direct factor. One can cite, as actions to reduce final disposal amount that dischargers can take, (2) technological measures at the production stage and (3) technological measures after discharge. Factor (2) means reducing wastes generated in conjunction with production activities by means such as changes in production processes and raw materials. Factor (3) deals with wastes after they are generated. This means, for example, reducing the volume of waste that would ordinarily be sent directly to final disposal sites by intermediate treatment. Other possible actions by which dischargers reduce the final disposal amount in their own prefectures are (4) sending waste to out-of-prefecture disposal sites and (5) illegal dumping.

This analysis will deal only with factors (1) through (3). Factor (1) is represented by the very indicator of industry's activity level (the effect of business conditions). Factor (2) is represented by the rate of industrial waste generated to the industrial activity level, that is, the amount of industrial waste generated per unit production value (the effect of production technology). Factor (3) can be divided into three sub-factors depending on the stage at which measures are implemented. Factor (3a) is the ratio of industrial waste discharged to the amount generated, and signifies the effectiveness of recycling at the source. Factor (3b) is the ratio of industrial waste transported to the amount generated, and signifies the discharger's "effect of internal treatment." Factor (3c) is the ratio of final disposal amount to amount of industrial waste transported, and it signifies the "effect of intermediate treatment" after outsourced waste management. The relationship of these five factors is illustrated by the following equation. Elements on the right side correspond to factors (1) through (3c) in order from the right.

$$\begin{aligned}\text{Final disposal amount} &= \frac{\text{Final disposal amount}}{\text{Transported amount}} \times \frac{\text{Transported amount}}{\text{Discharged amount}} \times \frac{\text{Discharged amount}}{\text{Generated amount}} \\ &\times \frac{\text{Generated amount}}{\text{Activity level}} \times \text{Activity level}\end{aligned}$$

This is an identical equation, with equality being self-evident. At the same time, the grounds for using these five factors as the factors that explain changes in final disposal amount are not necessarily self-evident. In this paper the grounds for adopting this equation are: (1) statistics corresponding to these factors were available, (2) in satisfying (1), decomposition into the most factors is possible, and (3) the equation logically conforms to the waste flow from generation to final disposal.

4. Decomposition Analysis Results

4.1 Overview of Analysis Results

Table 1 presents the results of the decomposition analysis using the above data. It adds the business conditions factor to 26 industrial sectors and 20 types of industrial waste, and is decomposed into a total of 2,106 factors. However, data actually exist for 622 factors. Each of the table's elements corresponds to the factors. Numerical values shown for each factor indicate the extent to which that factor helped decrease the final disposal amount. For example, the value −305 appears under construction industry Factor (1). This indicates that the contribution of the construction industry's business conditions factor is a 30,500-t decrease in final disposal amount, which is 19% of the decrease in final disposal amount during the time period covered. But there are also factors that contributed to an increase. For example, there is an increase of 29,100 t by Factor (3-3), which is construction industry waste asphalt, and an increase of 27,400 t by Factor (2), which is waste plastic from the plastic industry. Overall, 220 factors contributed to decreases (a total decrease of nearly 400,000 t) and 178 factors contributed to increases (a total increase of nearly 240,000 t), while there were 224 factors which did not change much (those which changed less than 100 t after rounding).

Table 1. Result of decomposition analysis of change from FY2000 to FY2004.

[100 t]		Construction	Food	Beverages	Textile	Wood products	Paper and pulp	Chemicals	Petroleum and coal	Plastics	Rubber	Cement & ceramics	Iron & steel	Non-ferrous metal	Metal products	General machinery	Electric machinery	Transport equipment	Computer and electronics	Other manufacturing	Wearing apparel	Furniture	Printing and publishing	Leather	Transportation	Wholesale and retail trade	Services
Factor (1)		-305	-4	2	-3	-14	-4	29	1	-73	5	-19	-17	13	-0	6	11	30	-0	-0	0	-1	-0	0	-1	-4	0
Factor (2)	Cinder		8					33				2															
	Sludge	128	-10		2		22	-4	3	149	-3	45		-2	-2	39	-3	-14		0		5			2	-5	0
	Waste oil		1			0	2	1	-0	1	0	41	0	-1	-0	1	11	-4				0			-0	2	0
	Waste acid							0	0	1		0		0	0		-3	0									
	Waste alkali		0					0	1	37		1	0	18	2	3	4	1					0				
	Waste plastic	12	3	0	1	0	2	3	0	274	-4	4	4	-6	-6	5	3	-7	-0	2		2	-3		-5	-7	-0
	Waste tire										-3						-0								-8	-18	-0
	Used paper	2					1																				
	Wood waste	9				-0	0															0					
	Waste textile	1																									
	Animal & plant residue		-8	33																							
	Waste rubber										6							0									
	Metal scraps	1	-3		0			1		1	0	0		0	-0	6	-1	-3				0	0		-0	2	0
	Waste glass	14	0			-13		-0	-0	8		124	2	0	5	3	1	-0							0	-1	
	Slag											2	49	6		-2		-68									
	Waste concrete	73										1													0	-3	
	Waste asphalt	148							0																		
	Other debris	58																									
	Fly ash							-3	21			1		-0													
	Other waste	4																									
Factor (3a)	Cinder		0					0				0															
	Sludge	0	-0		0		0	0	-0	0	0	0		-0	0	0	0	0		0		0			0	0	0
	Waste oil		-0			0	0	-0	0	0	0	0	0	0	0	-0	-7	-1				0			0	0	0
	Waste acid							0	0	0		0		0	0		-1	0									
	Waste alkali		0					0	-0	-2		0	0	0	0	0	-1	0					0				
	Waste plastic	0	-2	0	-0	1	0	-5	0	-11	1	-1	0	-3	1	-0	-0	-1	0	0		0	0		0	-0	0
	Waste tire										0						0								0	0	-0
	Used paper	0					0																				
	Wood waste	0				0	-0															0					
	Waste textile	0																									
	Animal & plant residue		0	-0																							
	Waste rubber										1							0									
	Metal scraps	-0	-5		0			-0		0	0	0		0	0	12	1	-7				0	0		-0	1	0
	Waste glass	6	0			0		0	0	0		3	0	0	0	0	-1	0							0	0	
	Slag											0	-6	0		0		0									
	Waste concrete	8										0													0	0	
	Waste asphalt	8							0																		
	Other debris	0																									
	Fly ash							0	0			0		0													
	Other waste	0																									

Factor (3b)	Cinder		-9					-15				-1															
	Sludge	-9	36		1		-15	-163	3	105	2	-26		-16	-3	-43	0	-5		0		-5			0	-1	-0
	Waste oil		0			0	0	5	0	1	0	0	0	0	0	0	0	1				0			-0	0	0
	Waste acid							0	0	0		0		0	0		0	0									
	Waste alkali		0					5	0	-18		0	0	2	0	0	0	0					0				
	Waste plastic	-0	3	0	2	0	1	6	0	72	0	0	-3	0	0	0	-0	-0	0	0		0	0		0	0	0
	Waste tire										-4						0								0	0	0
	Used paper	0					1																				
	Wood waste	2				1	-0															0					
	Waste textile	0																									
	Animal & plant residue		5	-40																							
	Waste rubber										-2							0									
	Metal scraps	0	0		0			-0		-0	0	0		0	0	0	0	-2				0	0		0	0	0
	Waste glass	-0	0			0		0	0	0		125	0	0	0	0	0	0							0	0	
	Slag											0	0	-8		0		17									
	Waste concrete	-34										-1													0	3	
	Waste asphalt	-65							0																		
	Other debris	0																									
	Fly ash							0	0			0		0													
	Other waste	0																									
Factor (3c)	Cinder		-11					-42				-42															
	Sludge	-377	-75		-8		-29	-239	-13	8	-10	-52		6	-0	-25	-13	4		0		1			-2	4	-2
	Waste oil		-0			0	-3	-23	-2	-1	0	-40	1	-2	2	2	-18	-1				0			-1	3	0
	Waste acid							0	0	2		0		0	0		-19	0									
	Waste alkali		1					-16	-2	-33		-1	0	-29	-2	2	-22	-4					0				
	Waste plastic	-11	-14	1	-1	-1	-3	-8	2	-244	-37	-7	0	-14	-2	-2	-9	-16	-0	-3		-2	-3		-5	3	-1
	Waste tire										-9						-1								-10	-27	-1
	Used paper	-3					-3																				
	Wood waste	-10				-0	-1															0					
	Waste textile	-1																									
	Animal & plant residue		-36	-19																							
	Waste rubber										-10							0									
	Metal scraps	-7	-15		0			1		-2	-1	0		0	1	-17	1	5				0	0		-0	2	0
	Waste glass	-19	0			17		-2	0	0		-373	2	-6	-4	-5	-11	-1							0	0	
	Slag											-1	-144	-2		-3		-99									
	Waste concrete	-153										-2													0	-4	
	Waste asphalt	291							0																		
	Other debris	-184																									
	Fly ash							-11	-22			-2		-9													
	Other waste	4																									

Because "Industrial Waste Fact-Finding Survey" has no activity level data for the electric utility and water utility industries, those industries are excluded from this analysis. From FY2000 to FY2004 the industrial waste final disposal amount of all industries decreased by 177,400 t, of which the electric and water utility industries accounted for 16,200 t. The decrease remainder of 161,200 t coincides with the total change in all factors in Table 1. This makes it possible to verify the decomposition analysis.

As this shows, many factors contributed to changes in final disposal amount, but those whose contributions were large in absolute amount are limited to just a few. Final disposal amount of the analyzed industries decreased 161,200 t, and of the factors responsible for decline, the main nine factors can explain 135% of the decrease amount. The total of the main eight increase factors comes to 83% of the decrease amount's absolute value. Figure 1 identifies the factors that made large contributions to this absolute value. Industrial sectors with large contributions were construction, cement and ceramics, plastics, chemicals, and steel. Industrial waste categories with large contributions were sludge, waste glass, debris (waste asphalt, waste concrete, and other debris), and waste plastic.

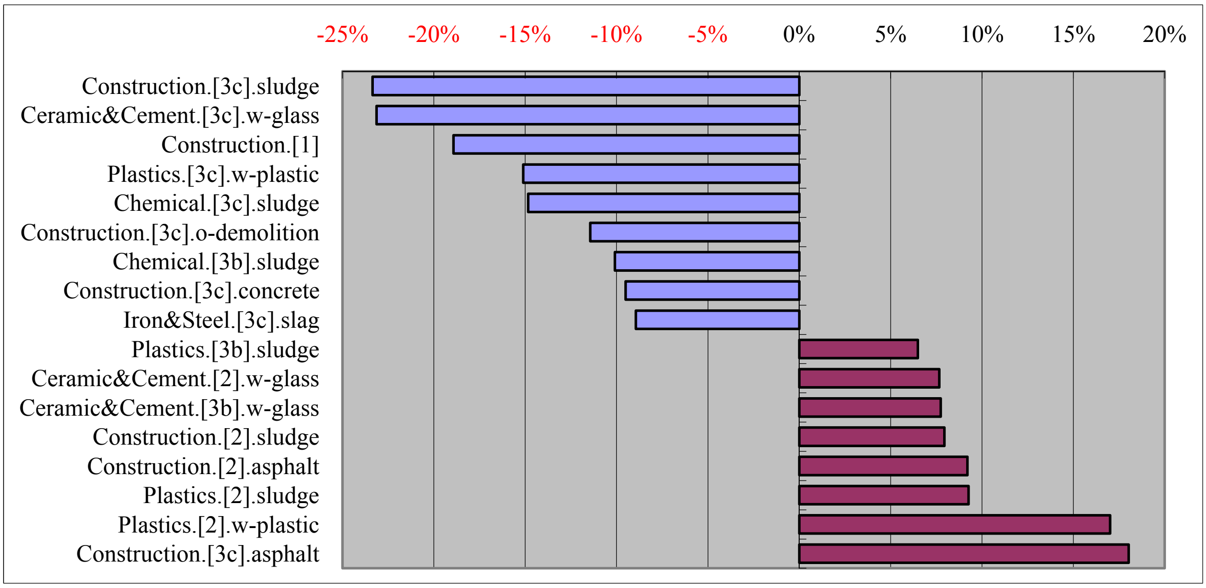


Figure 1. Factors contributing greatly to change from FY2000 to FY2004 in industrial waste final disposal amount.

4.2 Cautions to Observe When Interpreting Decomposition Analysis Results

One can see places in Table 1 and Figure 1 that, in the business categories where Factor (1) (the effect of business conditions) contributed to a decrease, Factor (2) (the effect of production technology) sometimes contributes to an increase. Some examples are construction, plastic manufacturing, and cement and ceramics. When interpreted by individual factors, this means that, in the case of Factor (1), less waste was generated by that industry because its production declined, and, in the case of Factor (2), more waste was generated per unit production value. In other words, it appears to signify a change to a production method that more readily generates waste.

But another interpretation is possible in consideration of the connection between Factors (1) and (2). The statistical data upon which Factor (1) is based indicate, for example, the value of completed jobs on original contracts in the construction industry, and the value of manufactured goods shipped in the manufacturing industry. Both are on a value basis. Ordinarily when the same production technology is used and if production volume remains unchanged, then the amount of waste discharged should also be unchanged. But under circumstances in which product price tends to fall, the value of products shipped will decrease even with no change in the level of production (shipping) volume. When such a situation arises, apparently Factor (1) serves to decrease while Factor (2) serves to increase. Analyses must clearly distinguish between such apparent contributions while taking note of not only the value of shipped goods, but also statistics on production volume and product prices.

In the construction industry, even jobs that cost the same amount generate much different amounts and kinds of wastes depending on the specifics of the projects. For example, ordinary street construction would presumably generate hardly any sludge, but tunnel construction would generate much sludge. As such, a realistic analysis would be difficult unless one takes into account not only the value of a completed job on the original contracts, but also what the job involved.

Statistics on the value of completed jobs on original contracts also have problems. Construction projects sometimes take several years, but statistics for any one year count projects that were completed that year. On the other hand, much of the waste is often generated during the initial stage of a project. It is therefore possible that waste generated and the value of completed jobs on original contracts will be counted in different fiscal years. This creates a problem for analysis especially when there are large fluctuations in the value of completed jobs every year. For that reason, this analysis confirms the fluctuation in the value of completed jobs for the analysis time period (Figure 2). Until 2001 they held steady, and since that time have tended to decline, mainly in the area of public works. As there is no large fluctuation in the year-to-year value of completed jobs, it appears that this presents little problem to this analysis.

When the same product in the same industry type contributes to both increases and decreases, as in cement and ceramics, and waste glass, possible influences include, for example, outsourcing the treatment of waste previously managed in house. In such a situation, even if there is no change at all in the actual waste flow, the mere change of waste treatment from in house to a contractor contributes to increased internal treatment and decreased intermediate treatment.

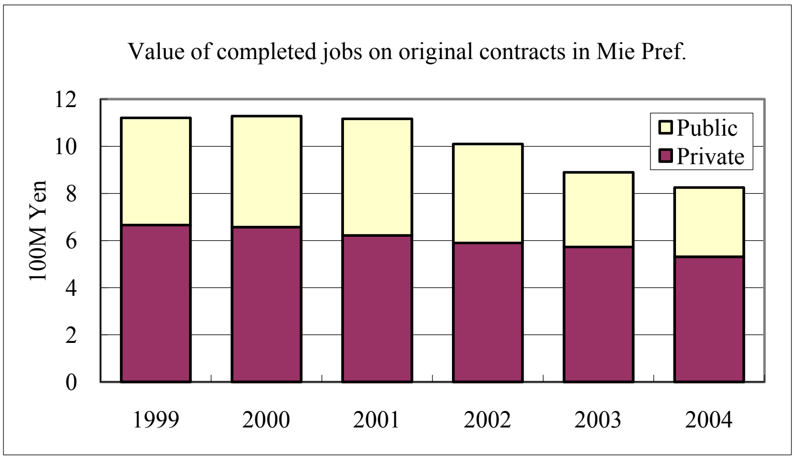


Figure 2. Identifying changes in construction industry activity level

Source: Prepared with Ministry of Land, Infrastructure and Transport, "Study on Construction Project Implementation Statistics."

4.3 Decomposition Analysis Summation

Major factors cited in Figure 1 may sometimes have a large effect as individual factors, but nevertheless will on the whole make a small contribution to the overall waste flow under consideration because increases and decreases mutually cancel one another when factors following one another closely. An example would be waste plastic discharged by the plastic industry. At the production stage, these factors contribute to a 27,400-t increase, but at the intermediate treatment stage they contribute to a 24,400-t decrease, leaving a 3,000-t increase after canceling. One can find similar relationships in cement and ceramics, and waste glass.

After eliminating such influences, the main factors contributing largely to a decrease in final disposal amount in view of total flow are as follows: (A) Chemical industry sludge (over 40,000 t), (B) construction industry debris (nearly 34,000 t), (C) construction industry activity level decline (over 30,000 t), and (D) construction industry sludge (nearly 25,000 t). On the other hand, we can also cite factors that contribute greatly to increases in final disposal amount in view of total flow: (E) Construction industry waste asphalt (nearly 44,000 t) and (F) plastic industry sludge (over 25,000 t).

Finally, allow me to briefly review the relationship between these main decrease factors and industrial waste taxes. First, (A) chemical industry sludge is the contribution of the Ishihara Sangyo Yokkaichi plant. The sludge has been statistically reduced apparently by recycling, but in fact Ishihara renamed it Feroshilt and dumped it illegally (on the Feroshilt issue, see for example Sugimoto (2007)). This contribution is only an apparent reduction, and it is a mistake to render an assessment on this basis that instituting the industrial waste tax was effective in reducing final disposal amount. Next is (C) construction industry activity level decline. As Figure 2 shows, this happened because of the decrease in public works during the analysis period, and therefore this contribution too cannot be ascribed to the tax. In the case of (B) and (D), both signify the encouragement of C&D waste recycling. Although influence by the tax is conceivable, the Construction Waste Recycling Law, enacted in 2000, was also implemented at this time. It will be necessary to compare Mie with prefectures that do not have industrial waste taxes, and to perform investigations that specifically address individual examples. The above discussion suggests that only a few of the main decrease factors are connected to the industrial waste tax.

5. Future Challenges

The above decomposition analysis was able to specify factors that in terms of statistics contributed greatly to changes in final waste disposal amount. Future research is charged with the task of examining specified individual factors, clearly distinguishing their apparent contributions as in the previous section, and identifying instances in which specific measures actually taken by businesses led to final disposal decreases (instances of intentional decreases). Whether it is possible to marginally verify if Mie Prefecture's industrial waste tax has had any effect will depend on the proportion of the total final disposal amount decrease that is attributable to reduction contributions which are due to efforts for intentional reduction. To be more precise, it will be necessary to examine instances of intentional decreases in order to identify those which were definitely catalyzed by introduction of the industrial waste tax. Further, a long-term task will be to perform the same kind of analysis for prefectures that have instituted industrial wastes differently and determine whether differences in institutional design relating to the effectiveness of incentives to reduce waste generation have influenced changes in actual industrial waste final disposal amount.

References

Chugoku Bureau of Economy, Trade and Industry (2006), *Chihou Jichitai ni yoru Sangyo Haikibutu ni kakawaru Zei no Donyu ni tomonau Sangyokai heno Eikyo tou Chousa Hokokusho* [*Report of the Survey on the influences to the Industry of the introduction of the taxes on Industrial Wastes by Municipalities*], (downloadable from http://www.chugoku.meti.go.jp/research/h17fy/sangyohaiki/sangyohaiki.htm) (in Japanese).

Conrad, K. (1999), “Resource and Waste Taxation in the Theory of the Firm with Recycling Activities,” *Environmental and Resource Economics*, Vol. 14, pp. 217-242.

Dinan, T. M. (1993), “Economic efficiency effects of alternative policies for reducing waste disposal”, *Journal of Environmental Economics and Management*, Vol. 25, pp. 242-256.

Fujikawa, K. (1999), *Gurobaru Keizai no Sangyo Renkan Bunseki* [*Input-Output Analysis of the Global Economy*], Sobunsha Publishing Co., Tokyo, Japan (in Japanese).

Fullerton, D. and T. Kinnaman (1995), “Garbage, Recycling, and Illicit Burning or Dumping,” Journal of Environmental Economics and Management, Vol. 29, pp. 78-91.

Hoekstra, R. (2005), *Economic Growth, Material Flows and the Environment: New applications of structural decomposition analysis and physical input-output tables*, Edward Elgar, Cheltenham, UK.

Kohn, R.E. (1997), *Pollution and the Firm*. Cheltenham, UK: Edward Elgar Publishing.

Masui, T., Y. Matsuoka, and T. Morita (2000), “Kankyo to Keizai o Togoshita Oyo Ippan Kinko Model ni yoru Kankyo Seisaku no Koka Bunseki [Development of Applied General Equilibrium Model Integrated Environment and Economy],” *Kankyo System Kenkyu Ronbunshu* [*Selected Papers on Environmental Systems Research*] 28, pp.467-475 (in Japanese).

Masui, T., Y. Matsuoka, and T. Morita (2001), “Oyo Ippan Kinko Model wo mochiita Sogo Kankyo Zei no Koka Bunseki [Evaluation of the Impact of Comprehensive Environmental Tax Using an Applied General Equilibrium Model],” *Kankyo Keizai Seisaku Gakkai Nenpo*[*Annual Report of Society for Environmental Economics and Policy Studies*]6, pp.69-82 (in Japanese).

Okushima and Yamashita (2005), “A General Equilibrium Analysis of Waste Management Policy in Japan,” *Hitotsubashi Journal of Economics*, Vol. 46, No. 1, 2005, pp. 111-134.

Sasao, T (2010), “Sangyo Haikibutsu Zei no Saishu Shobun Sakugen Kouka ni kansuru paneru deta Bunseki [The Effect of Industrial Waste Taxes: A Panel Data Analysis of Final Disposal of Industrial Waste in Japan],” *Kankyo Keizai Seisaku Kenkyu* [*Review of Environmental Economics and Policy Studies*], Vol. 3, No. 1, pp. 55-67 (in Japanese).

Sugimoto, H. (2007), *Akai Tsuchi, Feroshilt: Naze Kigyo Hanzai ha Kurikaesareta noka* [*Red earth, Feroshilt: Why corporate crime was repeated?*], Fubaisha, Inc., Nagoya, Japan (in Japanese).

Washida, T. (2004), *Kankyo Seisaku to Ippan Kinko* [*Environmental Policy and General Equilibrium*], Tokyo, Keiso Shobo (in Japanese).

Yamashita and Yokemoto (2004), “Naze Mie Ken deha Sampai Saishu Shobunryo ga gekigen shitanoka? [Why the Final Disposal Amount of Industrial Wastes decreased sharply in Mie Prefecture?],” *Kankyo to Kogai* [*Research on Environmental Disruption*], Vol. 33, No. 4, pp. 48-55 (in Japanese).

GRESHAM'S LAW IN

ENVIRONMENTAL PROTECTION

Ya-Po Yang[a] and Jin-Li Hu[b]

[a] Institute of Business and Management, National University of Kaohsiung, Taiwan

E-mail: yapo@nuk.edu.tw

[b] Institute of Business and Management, National Chiao Tung University, Taiwan

E-mail: jinlihu@yahoo.com

Abstract. *Under incomplete environmental enforcement, the high-cost firm may strategically violate the environmental standard in order to deter the low-cost firm from entering the market - that is, a phenomenon similar to Gresham's Law in which bad money drives out good money may occur. Tightening environmental regulation without increasing probability and penalties hence helps drive out the low-cost firm from the market. This explains why serious pollution and inefficient production co-exist in developing economies.*

Keywords: Incomplete environmental enforcement; Gresham's Law; Detection probability; Penalties

JEL Classification: L13, Q53

1 Introduction

Due to the budget constraint of enforcers and self-interest of firms, environmental enforcement is incomplete in practice. Especially in an oligopolistic market, firms strategically act against environmental regulations in order to maximize their own profits, causing failures in environmental regulations. Therefore, it is possible for a violating firm to resist environmental enforcement by luck, and hence has economic and environmental effects. However, this is unfair competition for a compliant firm, which constitutes Gresham's Law in environmental regulations.

Due to incomplete enforcement, firms in the ground market may be inspected more easily than those in the underground market. In China the ratio of officially qualified one-shot tableware has gone down every year since 2002, because underground factories can survive more easily than law-obedient ones by avoiding the legally required environmental protection costs (SINA 2005). In Taizhou of Zhejian Province where metal-recycling industries dominate, under incomplete enforcement heavily polluting firms survive more easily by using low-cost and high-polluting burning methods to get rid of the insulation material outside the wires. As a result, the environmental Gresham's Law occurs when the law-obedient firms bear higher production costs (Zhejian On Line 2005). A similar phenomenon also takes place in recreational fishery located in Taiwan's Penghu Islands (Taiwan Environmental Information Center 2007). The legal businesses are more often inspected than underground ones, decreasing the costs of the underground firms and hence deteriorating the bio-environment.

Moreover, products with high environmental quality are more expensive than those having low environmental quality. Ninety percent of energy-saving light bulbs are produced in China, yet only 21% of bulbs in China are energy-saving. This is because consumers prefer to buy cheaper bulbs which are not energy-saving, resulting in another example of the environmental Gresham's Law (People 2007). Degradable plastic bags are not popular in China since they are more expensive, as evidenced in 2006 when China had plastic waste of over 300 million tons. Producers of degradable plastic bags complain that they are suffering from the environmental Gresham's Law (China Economic Net 2008).

Becker (1968) is the pioneer in the formal economic modeling of incomplete enforcement. In an incomplete enforcement environment in which the verdict probability is less than 100%, a rational economic player can commit a crime to earn surplus. Becker's framework of crime and punishment is widely applied to analyze the incomplete environmental enforcement, for example in Harford (1978, 1991), Viscusi and Zeckhauser (1979), Harrington (1988), Jones (1989), Kambhu (1989), Shaffer (1990), Xepapadeas (1991), Malik (1990, 1993), Keeler (1991), Segerson and Tietenberg (1992), Swierzbinski (1994), Garvie and Keeler (1994), Huang (1996), Lear and Maxwell (1998), and Hu et al. (2004).

Harford (1978), Viscusi and Zeckhauser (1979), and Jones (1989) assume the market structure of perfect competition and discuss effects of environmental standards and penalties on environmental quality. Kambhu (1989) and Shaffer (1990) study the evasive behavior of the firm to reduce detective probability of a violation. Malik (1990) and Keeler (1991) analyze the efficiency of a transferable discharge permit system when firms may violate environmental regulations. Harrington (1988), Harford (1991), Segerson and Titenberg (1992), Malik (1993), and Swierzbinski (1994) research the incentive mechanism design of punishment when firms may not be complying with environmental regulations.

Most studies in the related literature apply the principal-agent model to analyze the incomplete enforcement problem, but they assume only one firm under the incomplete environmental enforcement. Strategic interaction among regulated firms will complicate and hence distort the effect of incomplete environmental enforcement. To the best of our knowledge, Lear and Maxwell (1998) is the only paper that formally models an n-oligopoly market structure under incomplete enforcement, but they do not take into account the cost difference and environmental technology adoption. Since they do not take into account the asymmetric cost issue, only the symmetric Nash equilibrium results are discussed.

The cost differentiation and decision to enter and exit the market have been important issues in industrial economics. For example, the recent literature taking cost differentiation into account includes Helder (2005), Farzin and Akao (2006), and Piercarlo (2006), while that endogenizing the firm's decision to enter or exit the market consists of Andrea and Giordano (2006) and Bayer (2007). In fact, firms try to gain market share by many means, including strategic environmental protection behavior. However, the existing literature on environmental policy seldom simultaneously takes into account cost differentiation and the endogenous decision to enter or exit the market.

If the cost differentiation, endogenous decision to enter or exit the market, and strategic interaction between oligopolistic firms are taken into account, then it may not be necessarily true that a more rigorous environmental standard will always promote environmental quality. The high-cost firm may get away with its violation and hence may save on its environmental cost, thus increasing its competitiveness in the market. In other words, it is possible for Gresham's Law to show up in environmental protection.

This paper builds up a three-stage game to analyze the welfare effects of incomplete environmental enforcement in an oligopoly market structure. This paper is organized as follows: Following the introduction, Section 2 offers the basic model in which a three-stage game is built. Section 3 analyzes the effects of the expected fines and enforcement probability on environmental quality. Finally, Section 4 concludes this paper.

2 THE BASIC MODEL

2.1 Model Setting

Assume that firms x and y produce a homogeneous product. The inverse market demand function is $p = a - b(q_x + q_y)$. There is pollution emission in the production of this product and the consumers are unable to distinguish the exact pollution levels. The fixed marginal costs of production for these two firms are c_x and c_y, respectively. If $c_x = c_y$ ($c_x \neq c_y$), then these two firms are homogeneous (heterogeneous). We further assume that the production and pollution abatement costs are strongly separable as in Chiou and Hu (2001). There is no fixed cost for both production and pollution abatement.

The initial per output emission is k for both firms. The upper bound of emission regulated by the government is e. Any actual emission exceeding e is a violation. A smaller value of e implies a more rigorous environmental standard. For a compliant firm, per output emission after abatement is $k - A$, where A is the per output abatement level. Per output environmental damage is therefore $D(e) = \overline{D} \cdot e = \overline{D}(k - A)$, where $\overline{D}$ is the fixed marginal damage in monetary terms.

We denote the marginal cost of abatement by $MC(h)$, where h is the pollution abatement amount and $MC'(h) > 0$. The abatement cost per output is thus $s = \int_0^A MC(h)dh = \int_0^{k-e} MC(h)dh$, which is a function of A (or e). It is straightforward that $\frac{ds}{de} = -\frac{ds}{dA} = -MC(k-e) = -MC(A) < 0$, implying that the abatement cost per output increases with a more rigorous environmental standard.

Per output environmental damage can hence be expressed as $D(s) = \overline{D}(k - A(s))$ with $A(0) = 0$ and $D'(s) < 0$.

In order to simplify the analysis, per output environmental cost s is used to measure the rigorousness of the environmental standard. A higher value of s implies a more rigorous environmental standard. Assume that these two firms are risk-neutral and face the same enforcement probability θ with $0 < \theta < 1$. The penalty is a fixed amount of fines f. The above assumptions are consistent with Montero (2002) who compares quantity and price regulations under incomplete environmental enforcement by assuming constant detection probability and fines. Although there is a range of fines or penalties in each country's environmental laws, in practice it is very difficult to judge the degree of violation and hence a fixed amount of fines will be applied to violations at different degrees.

This game has three stages. Taking the environmental standard, enforcement probability, and fines as given, in the first stage each firm decides whether or not to enter the market. In the second stage each firm in the market simultaneously decides whether or not to comply with the environmental standard. In the third stage each firm in the market chooses its output quantity. If there is only one firm in the market, then it is a monopoly. If there are two firms in the market, then they engage in the Cournot competition.

Figure 1 depicts the extensive form of the basic model. We apply the solution concept of subgame perfect Nash equilibrium (SPNE) to solve this game by backward induction.

[Figure 1 about here.]

2.2 The Nash Equilibrium Outcomes in Stage 3

In stage 3, each firm in the market makes a decision of its own quantity. The expected profit function of firm *i* can be written as:

$$\begin{aligned} E\pi_i &= \theta\{[a-b(q_i+q_j)]q_i - C_i q_i - F_i\} \\ &\quad + (1-\theta)\{[a-b(q_i+q_j)]q_i - C_i q_i\}, \text{ if } C_i = \begin{cases} c_i + s, \\ c_i, \end{cases} \text{, then } F_i = \begin{cases} 0, \\ f, \end{cases} \forall i, j = x, y \\ &= [a-b(q_i+q_j)]q_i - C_i q_i - \theta F_i, \end{aligned} \quad \textbf{(1)}$$

where C_i is the total marginal cost of firm *i*; if firm *i* complies with the environmental standard, then $C_i = c_i + s$ with expected penalties of $\theta F_i = 0$; if firm *i* violates the environmental standard, then $C_i = c_i$ with expected penalties of $\theta F_i = \theta f$.

According to Equation (1), the profit-maximizing decision of firm *i* under two possible scenarios are as follows.

2.2.1 Firm *i* is a Monopoly in the Market

If firm *i* is a monopoly in the market, then $q_j = 0$ and firm *i* will choose the monopoly output level $q_i = \frac{a - C_i}{2b}$ to maximize its own profit, where C_i is per output cost of firm i. If firm i complies with the environmental standard, then $C_i = c_i + s$ and its expected profit is $\frac{(a - c_i - s)^2}{4b}$. If firm *i* violates the environmental standard, then $C_i = c_i$ and its expected profit is $\frac{(a - c_i)^2}{4b} - \theta f$. Therefore, the monopoly firm *i*'s expected profit function is:

$$E\pi_i = \begin{cases} \frac{(a - C_i)^2}{4b} \\ \frac{(a - C_i)^2}{4b} - \theta f \end{cases} \text{if } C_i = \begin{cases} c_i + s \\ c_i \end{cases} \quad i = x, y \quad \textbf{(2)}$$

2.2.2 Two Firms Enter the Market

When two firms enter the market, they engage in the Cournot competition. The Nash equilibrium outputs of firms *i* and *j* are $\frac{(a-2C_i+C_j)}{3b}$ and $\frac{(a-2C_j+C_i)}{3b}$, respectively, where C_i and C_j are per output costs for firms *i* and *j*. If firm *i* complies with the environmental standard, then $C_i = c_i + s$ and its expected profit is $\frac{[a-2(c_i+s)+C_j]^2}{9b}$. If firm *i* violates the environmental standard, then $C_i = c_i$ and its expected profit is $\frac{[a-2c_i+C_j]^2}{9b} - \theta f$. To sum up, firm *i*'s expected profit function can be expressed as:

$$E\pi_i = \begin{cases} \dfrac{[a-2C_i+C_j]^2}{9b} \\ \dfrac{[a-2C_i+C_j]^2}{9b} - \theta f \end{cases}, \quad \text{if } C_i = \begin{cases} c_i + s \\ c_i \end{cases}, \; i = x, y. \quad \textbf{(3)}$$

2.3 The Nash Equilibrium Outcomes in Stage 2

With the expectation of the Nash equilibrium outcomes in Stage 3, each firm in the market makes its own environmental protection decision. When firm *i* is a monopoly, if $\frac{(a-c_i-s)^2}{4b} > \frac{(a-c_i)^2}{4b} - \theta f$, then it is more profitable for firm *i* to comply with the environmental standard; otherwise, if $\frac{(a-c_i-s)^2}{4b} < \frac{(a-c_i)^2}{4b} - \theta f$, then it is more profitable for firm *i* to violate the standard.

When there is a duopoly in the market, if $\frac{[a-2(c_i+s)+C_j]^2}{9b} > \frac{[a-2c_i+C_j]^2}{9b} - \theta f$, then firm *i* will comply with the environmental standard; otherwise, if $\frac{[a-2(c_i+s)+C_j]^2}{9b} < \frac{[a-2c_i+C_j]^2}{9b} - \theta f$, then firm *i* will violate the standard.

2.4 The Nash Equilibrium Outcomes in Stage 1

In stage 1 a firm will enter the market as long as there is a positive expected profit for it to do so. Therefore, provided that firm j is not in the market, if firm *i* can enjoy a positive expected profit by entering the market with either compliance or violation, i.e., $\max\left\{\frac{(a-c_i-s)^2}{4b}, \frac{(a-c_i)^2}{4b}-\theta f\right\} > 0$, then it enters the market; otherwise, firm *i* stays out of the market. Similarly, when firm j is in the market, firm *i* chooses to enter the market as long as $\max\left\{\frac{[a-2(c_i+s)+C_j]^2}{9b}, \frac{[a-2c_i+C_j]^2}{9b}-\theta f\right\} > 0$, which implies a positive expected profit for firm *i* to enter the market; otherwise, firm *i* stays out of the market.

3 EFFECTS OF PENALTIES ON ENVIRONMENTAL QUALITY

3.1 A Loose Environmental Standard

Without losing generality, plenty of existing literature such as Markusen et al. (1993) and Motta and Norman (1996) demonstrate how changes in parameter values affect equilibrium outcome.[1] Following the analytic frameworks of Markusen et al. (1993) and Motta and Norman (1996), we also start with the situation for a loose environmental standard of a set of parameters (a = 4, b = 1, c_x = 1, and s = 1), which is shown in Figure 2. Note that a proportional expansion or contraction in these parameters will not change the relative positions of equilibrium regimes in Figure 2 at all and hence the following analysis loses no generality. In Figure 2 the horizontal axis is the expected fines of violation θf and the vertical axis is the marginal

[1] Markusen et al. (1993) discuss the location choice of two firms from two countries. They point out that any small policy changes may cause a shift in the equilibrium regime, hence making a drastic welfare change. Motta and Norman (1996) build up a three-country, three-firm model. They study how a free trade zone formed by two countries affects the foreign direct investment behavior of the third country's firm.

production cost of firm y (c_y). The line $c_y = 1$ is for reference when these two firms are homogeneous. The upper part of the line $c_y = 1$ represents firm y as the one with a higher production cost. On the contrary, the lower part of the line $c_y = 1$ represents firm y as the one with a lower production cost. Different combinations of (c_y, θf) may induce different SPNE outcomes. Furthermore, a parenthesis (•, •) in the figure represent the SPNE type in the area; C denotes the entry with a compliance strategy; N denotes the entry with a non-compliance strategy; and O represents a strategy of staying out of the market. As usually depicted in game-theoretic literature, the first strategy is of firm x and the second strategy is of firm y under each strategy combination.

In Figure 2 the line $E\pi_x^{\mathrm{CC}} = E\pi_x^{\mathrm{NC}}$ represents the profit indifference boundary for firm x to comply with or to violate the standard after its entry, provided that firm y is in the market and compliant. The right-hand side of the $E\pi_x^{\mathrm{CC}} = E\pi_x^{\mathrm{NC}}$ line is the area where the expected fines are relatively high and it is more profitable for firm x to comply with the environmental standard ($E\pi_x^{\mathrm{CC}} > E\pi_x^{\mathrm{NC}}$). On the contrary, the left-hand side of the line $E\pi_x^{\mathrm{CC}} = E\pi_x^{\mathrm{NC}}$ is the area where the expected fines are relatively low and it is more profitable for firm x to violate the environmental standard ($E\pi_x^{\mathrm{CC}} < E\pi_x^{\mathrm{NC}}$).

In Figure 2 the line $E\pi_y^{\mathrm{NC}} = E\pi_y^{\mathrm{NN}}$ represents the profit indifference boundary for firm y to comply with or to violate the standard after its entry, provided that firm y is in the market and non-compliant. The right-hand side of the line $E\pi_y^{\mathrm{NC}} = E\pi_y^{\mathrm{NN}}$ is the area where the expected fines are relatively high and it is more profitable for firm

y to comply with the environmental standard ($E\pi_y^{\text{NC}} > E\pi_y^{\text{NN}}$). On the contrary, the left-hand side of the line $E\pi_y^{\text{NC}} = E\pi_y^{\text{NN}}$ is the area where the expected fines are relatively low and it is more profitable for firm *y* to violate the environmental standard ($E\pi_y^{\text{NC}} < E\pi_y^{\text{NN}}$).

The line $E\pi_y^{\text{NC}} = 0$ represents the zero profit line for firm *y* to enter the market with compliance, provided that firm *x* enters with a violation. The lower part to the line $E\pi_y^{\text{NC}} = 0$ is where firm *y* can enjoy a positive profit with entry and compliance. The upper part of the line $E\pi_y^{\text{NC}} = 0$ is where firm *y* has a negative profit with entry and compliance.

For example, point *a* in Figure 2 is in the area $E\pi_x^{\text{CC}} < E\pi_x^{\text{NC}}$, $E\pi_y^{\text{NC}} > E\pi_y^{\text{NN}}$, and $E\pi_y^{\text{NC}} = 0$. On the one hand, if firm *x* enters and violates, then the best response for firm *y* is to enter and comply. On the other hand, provided that firm *y* enters and complies, the best response of firm *x* is to enter and violate. Therefore, the SPNE in the area containing point *a* is (N, C). Therefore, the SPNE in each regime of Figure 2 can be found by checking the rationality and incentive constraints.

From Figure 2, we know that if the combination of the marginal cost of firm *y* (c_y) and expected penalty (θf) lies in a regime in which a firm violates, then an increase in enforcement probability (θ) or penalties (f) will shift the combination of c_y and pf to the right, making the equilibrium type possibly change. If the changes in θ and f are very small such that c_y and pf only slightly change, then the SPNE outcome will not change. However, drastic changes in θ and f will shift the combination of (c_y, θf) to another area, hence changing the SPNE.

Figure 2 and the above discussion bring us to the following propositions.

Proposition 1. *Assume that the two firms are homogeneous. If the initial SPNE is that one firm complies and the other violates, then the government increasing penalties or enforcement probability may change the Nash equilibrium to be that the two firms comply, causing the environmental quality to be improved .*

[Figure 2 about here]

As Figure 2 shows, when the two firms are homogeneous ($c_x = c_y = 1$), if (C, N) is a Nash equilibrium, then (N, C) must be a Nash equilibrium, because these two firms have exactly the same conditions. Assume that $c_x = c_y = c$ and plug it into Figure 1. We immediately obtain that if (C, N) is an SPNE, then two of the corresponding incentive constraints are $E\pi_y^{\mathrm{CN}} = \frac{(a-c+s)^2}{9b} - \theta f > E\pi_y^{\mathrm{CC}} = \max\left\{\frac{(a-c-s)^2}{9b}, 0\right\}$ and $E\pi_x^{\mathrm{CN}} = \frac{(a-c-2s)^2}{9b} > E\pi_x^{\mathrm{NN}} = \max\left\{\frac{(a-c)^2}{9b} - \theta f, 0\right\}$. The latter constraint implies that $a - c - 2s > 0$. Therefore, $a - c - s > 0$ must hold, making $E\pi_y^{\mathrm{CC}} = \frac{(a-c-s)^2}{9b} > 0$ hold. In this situation, a small increase in fines (*f*) will not change the above inequalities and hence the SPNE outcomes will not change. However, if the increase in fines is sufficiently large, then the first incentive constraint will change to be $E\pi_y^{\mathrm{CN}} = \frac{(a-c+s)^2}{9b} - pf < E\pi_y^{\mathrm{CC}} = \frac{(a-c-s)^2}{9b}$, resulting in the outcome in which given that firm *x* enters and complies, firm *y* will choose to enter and comply.

Since $E\pi_x^{\mathrm{NC}} = \frac{(a-c+s)^2}{9b} - pf < E\pi_x^{\mathrm{CC}} = \frac{(a-c-s)^2}{9b}$, given that firm *y* enters and complies, the best response of firm *x* is also to enter and comply. Therefore, (C, C) will become the new SPNE. The total output level under (C, N) and (N, C) is $\frac{2a-2c-s}{3b}$ and that under (C, C) is $\frac{2a-2c-2s}{3b}$. Since the new SPNE (C, C) has a lower total output and compliance by both firms, its total pollution must be less and the environmental quality will improve.

Proposition 2. *Assume that the two firms are heterogeneous. Provided that the low-cost firm complies and the high-cost firm violates is the initial* SPNE, *if increasing enforcement probability and/or fines induces the high-cost firm to comply and the low-cost firm to violate to be the new* SPNE, *then the environmental quality will drop down.*

Proposition 2 can be illustrated as the shift of point b to point b' in Figure 2. The initial SPNE is (C, N). However, an increase in fines makes the new SPNE be (N, C), worsening off the environmental quality. The difference in the total pollution is hence:

$$\begin{aligned} E^{\mathrm{NC}}(s) - E^{\mathrm{CN}}(s) &= \tfrac{a-2c_x+c_y-2s}{3b}\overline{D}k + \tfrac{a-2c_y+c_x+s}{3b}\overline{D}(k - A(s)) \\ &\quad -[\tfrac{a-2c_y+c_x-2s}{3b}\overline{D}k + \tfrac{a-2c_x+c_y+s}{3b}\overline{D}(k - A(s))] \\ &= \overline{D}A(s)(\tfrac{a-2c_x+c_y-2s}{3b} - \tfrac{a-2c_y+c_x-2s}{3b}) \\ &= \overline{D}A(s)\tfrac{c_y-c_x}{b}. \end{aligned} \qquad \textbf{(4)}$$

Since firm y is the high-cost firm, the relation $c_y > c_x$ must hold, making the above difference in Equation (4) strictly positive. This implies the new Nash equilibrium has a higher total pollution amount. Proposition 2 can be compared with the findings of Viscusi and Zeckhauser (1979), Jones (1989), Kambhu (1989), Shaffer (1990), and Hu et al. (2004). A common conclusion of Viscusi and Zeckhauser (1979) and Jones (1989) is that an increase in the lump-sum fines will not worsen off the environmental quality. The main reason is that they assume the market structure of perfect competition and an increase in fines only reduces the expected profits of non-compliant firms and the profits of compliant firms are not affected at all. As a result, an increase in fines can only encourage perfectly competitive firms to comply with the environmental standards.

In the oligopolistic market structure adopted in this paper, an increase in fines can decrease the expected profit of a non-compliant high-cost firm as well as increase the marginal compliance cost of the low-cost firm. If the increase in the marginal compliance cost dominates the increase in marginal non-compliance cost for the low-cost firm due to an increase in fines, then it is likely for a compliant low-cost firm to turn out to be non-compliant. Therefore, the effects of the same environmental policy in an oligopoly market structure can be very different from that in a perfect competition market structure.

Kambhu (1989), Shaffer (1990), and Hu et al. (2004) endogenize the detection probability of a violation. If firms can take some evasive actions such as bribery and litigation to influence the verdict probability, then an increase in fines will promote the evasive actions and hence may result in lower pollution abatement efforts. This paper instead points out that even without evasive actions, the strategic interaction between oligopolistic firms will cause an increase in fines to have a worsening effect on the environmental quality.

Although Lear and Maxwell (1998) also study oligopolistic firms under incomplete environmental enforcement, in their paper all these n firms have the same compliance probability in equilibrium. Their result cannot explain why in an industry some firms comply and some others do not. This paper shows that compliance and non-compliance behaviors can co-exist in equilibrium. Moreover, an increase in the enforcement probability and/or fines may bring down the environmental quality by encouraging the low-cost firm to violate the environmental standard, hence reducing the occurrence of the environmental Gresham's Law.

Proposition 3. *Assume that the two firms are heterogeneous. Provided that one firm violates and the other one stays out of the market is the initial SPNE, if an increase in enforcement probability and/or fines makes two firms enter and comply to be the new one, then the environmental quality will improve.*

Proposition 3 can be illustrated by the shift of point c in the (N, O) regime to point c' in the (C, C) regime in Figure 2. The total pollution at the initial SPNE is $E^{\mathrm{NO}}(s) = \overline{D}k\,\frac{(a-c_x)}{2b}$ and that at the new SPNE (C, C) is $E^{\mathrm{CC}}(s) = \overline{D}(k - A(s))\,\frac{(2a-c_x-c_y-2s)}{3b}$. The difference in the two pollution levels is:

$$E^{\mathrm{CC}}(s) - E^{\mathrm{NO}}(s) = \overline{D}(-A(s)\,\frac{2a-c_x-c_y-2s}{3b} + k\,\frac{a-2c_y+c_x-4s}{6b}) \,. \qquad \textbf{(5)}$$

In Figure 2, $2s > a - 2c_y + c_x$ is one of the conditions supporting (N, O) regime to be a SPNE. Therefore, $4s > a - 2c_y + c_x$ must hold for the (N, O) regime, and hence the second term in Equation (5) must be negative, making the difference in Equation (5) negative sign. Proposition 3 also shows that if an increase in enforcement probability and fines can attract a new entrant to compete with the incumbent, then both firms may choose to comply and hence improve the environmental quality.

3.2 A Rigorous Environmental Standard

Without losing generality, Figure 3 depicts the situation with a more rigorous environmental standard. Compared to Figure 2, the only difference in parameters in Figure 3 is that the marginal environmental cost s is higher (s = 1.7). Note that a proportional expansion or contraction of these parameters will not change the relative positions of these equilibrium regimes in Figure 3.

[Figure 3 about here]

Comparing Figures 2 and 3, we can find the following differences caused by an increase in the marginal environmental cost (caused by a more rigorous environmental standard).

If the two firms are homogeneous (the dotted line $c_y = 1$ in Figure 1), then (N, O) or (O, N) will replace (N, C) or (C, N) in Figure 2 to be an SPNE outcome. This is because a more rigorous environmental standard will discourage firms to accommodate each other in the market.

If the two firms are heterogeneous and the difference in production cost is small, then low fines can induce the high-cost firm to co-exist with the low-cost firm by violating the standard (as shown by the triangular area in Figure 3).

If the two firms are heterogeneous and the difference in production cost is small, then it is possible to have an SPNE in which the high-cost firm becomes a non-compliant monopoly and the low-cost firm stays out of the market. This situation is illustrated by point d in Figure 3. At point d, firm y is the high-cost firm which monopolizes the market and violates the environmental standard. This is exactly a Gresham's Law phenomenon for environmental protection.

The Nash equilibrium shifting in Figure 3 is quite similar to that in Figure 2, but for one additional situation of Gresham's Law: A shift from point e to point e' in Figure 3 will make the SPNE shift from (C, N) to (N, O). This kind of shift can be caused by an increase in enforcement probability and/or fines. The difference in the total pollution then is:

$$\begin{aligned} E^{\mathrm{NO}}(s) - E^{\mathrm{CN}}(s) &= \overline{D}k\,\tfrac{a-c_x}{2b} - \overline{D}k\,\tfrac{a-2c_y+c_x+s}{3b} - \overline{D}(k-A(s))\,\tfrac{a-2c_x+c_y-2s}{3b} \\ &= \overline{D}k\,\tfrac{-a+2c_y-c_x+2s}{6b} + \overline{D}A(s)\,\tfrac{a-2c_x+c_y-2s}{3b}. \end{aligned} \quad \textbf{(6)}$$

From Figure 1, we know that $-a + 2c_y - c_x + 2s > 0$ is one of the conditions supporting the (N, O) regime and $a - 2c_x + c_y - 2s > 0$ is one condition supporting the (C, N) regime. It is then straightforward to show that the difference in Equation (6) is positive. Summing up the above discussion, we obtain the following proposition.

Proposition 4. *Assume that the two firms are heterogeneous. Provided that the initial SPNE is that the low-cost firm complies and the high-cost firm violates, if an increase in the enforcement probability and/or fines induces the low-cost firm to violate and the low-cost firm to exit to be the new one, then the environmental quality will worsen.*

Proposition 4 explains why the environmental Gresham's Law occurs in reality. In an economy of incomplete enforcement, a high-cost firm has an incentive to take a risk by violating the environmental regulation in order to reduce cost. If this high-cost firm is lucky with getting away with the environmental regulations, it can enjoy a cost advantage against the law-obedient firm while sacrificing the environmental quality.

4 CONCLUDING REMARKS

This paper builds up a three-stage game to discuss the strategic behavior of two heterogeneous firms under incomplete environmental enforcement. As this paper shows, the effects of environmental policies on oligopolistic firms can be very different from those on perfectly competitive firms. Moreover, a more rigorous environmental standard induces the high-cost firm to strategically violate the environmental standard so as to deter the entry of the low-cost firm, causing the Gresham's Law phenomenon in environmental protection which actually occurs in developing economies such as China and Taiwan. Therefore, when the environmental regulatory authority tries to increase enforcement probability, fines, and environmental standard, it must take into account the market structure and strategic behavior of firms.

Most developing economies promote environmental protection by more rigorous legislation and penalties, instead of improving their enforcement qualities. This immediately brings adverse effects on compliant firms, since non-compliant firms can get away with their violations and engage in 'environmental dumping'. In other words, the non-compliant firms can engage in unfair competition against the compliant firms, because the environmental enforcement is incomplete in most developing economies.

As shown by this paper under complete environmental enforcement, increases in enforcement probability, fines, and environmental standard unambiguously will promote compliance and hence environmental quality. Therefore, in the long run economies in the world need to improve their environmental enforcement quality in order to reduce the distortion caused by incomplete environmental enforcement.

REFERENCES

[1] Andrea, M. and M. Giordano, 2006, Advertising and Endogenous Exit in a Differentiated Duopoly, ***Recherches Economiques de Louvain/Louvain Economic Review***, 72:19-47.

[2] Bayer, C., 2007, Investment Timing and Predatory Behavior in a Duopoly with Endogenous Exit, ***Journal of Economic Dynamics & Control***, 31: 3069-3101.

[3] Becker, G., 1968, Crime and Punishment: An Economic Approach, ***Journal of Political Economy***, 76: 169-217.

[4] China Economic Net, 2008, China Has an Annual Plastic Waste Amount More than 300 Million Tons: Promoting Recycling Plastic Bags Is Extremely Difficult

(in Chinese). Downloaded from http://big5.ce.cn/xwzx/gnsz/gdxw/200801/14/t20080114_14220686.shtml.

[5] Chiou, J. R. and J. L. Hu, 2001, Environmental Research Joint Ventures under Emission Taxes, ***Environmental & Resource Economics***, 20: 129-146.

[6] Farzin, Y. H. and K. I. Akao, 2006, Environmental Quality in a Differentiated Duopoly, ***Fondazione Eni Enrico Mattei,*** Working Paper #2006.138.

[7] Garvie, D. and A. Keeler, 1994, Incomplete Enforcement with Endogenous Regulatory Choice, ***Journal of Public Economics***, 55: 141-162.

[8] Harford, J. D., 1978, Firm Behavior under Imperfectly Enforceable Standards and Taxes, ***Journal of Environmental Economics and Management***, 5: 26-43.

[9] Harford, J. D., 1991, Measurement Error and State-Dependent Pollution Control Enforcement, ***Journal of Environmental Economics and Management***, 21: 67-81.

[10] Harrington, W., 1988, Enforcement Leverage when Penalties are Restricted, ***Journal of Public Economics***, 37: 29-53.

[11] Helder, V., 2005, Tacit Collusion, Cost Asymmetries, and Mergers, ***Rand Journal of Economics***, 36: 39-62.

[12] Hu, J. L., C. H. Huang and W. K. Chu, 2004, Hierarchical Government, Bribery, and Incomplete Environmental Enforcement, ***Environmental Economics and Policy Studies***, 6: 177-196.

[13] Huang, C. H., 1996, Effectiveness of Environmental Regulations under Imperfect Enforcement and Firm Avoidance, ***Environmental and Resource Economics***, 8: 183-204.

[14] Jones, C. A., 1989, Standard Setting with Incomplete Enforcement Revisited, ***Journal of Policy Analysis and Management***, 8: 72-87.

[15] Kambhu, J., 1989, Regulatory Standards, Noncompliance, and Enforcement, ***Journal of Regulatory Economics***, 1: 103-114.

[16] Keeler, A. G., 1991, Noncompliant Firms in Transferable Discharge Permit Markets: Some Extensions, ***Journal of Environmental Economics and Management***, 21: 180-189.

[17] Lear, K. K. and J. W. Maxwell, 1998, The Impact of Industry Structure and Penalty Policies on Incentive for Compliance and Regulatory Enforcement, ***Journal of Regulator Economics,*** 14: 127-148.

[18] Malik, A. S., 1990, Markets for Pollution Control when Firms Are Noncompliant, ***Journal of Environmental Economics and Managemen***t, 18: 97-106.

[19] Malik, A. S., 1993, Self-Reporting and the Design of Policies for Regulating Stochastic Pollution, ***Journal of Environmental Economics and Management***, 24: 241-257.

[20] Markusen, J. R., E. R. Morey, and N. D. Olewiler, 1993, Environmental Policy when Market Structure and Plant Locations Are Endogenous, ***Journal of Environmental Economics and Management***, 24: 69-86.

[21] Montero, J. B. 2002, Prices versus Quantities with Incomplete Enforcement, ***Journal of Public Economics and Management***, 85: 435-454.

[22] Motta, M. and G. Norman, 1996, Does Economic Integration Cause Foreign Direct Investment?, ***International Economic Review,*** 37: 757-783.

[23] People, 2007, Institution is the Guarantee to Promote Energy-saving Bulbs (in Chinese). Downloaded from: http://energy.people.com.cn/BIG5/71894/6199710.html.

[24] Piercarlo, Z., 2006, Differentiated Duopoly with Asymmetric Costs, ***Journal of Economics and Management Strategy,*** 15: 999-1015.

[25] Taiwan Environmental Information Center 2007, The Gresham's Law in Penghu's Recreational Fishery (in Chinese), Downloaded from http://e-info.org.tw/node/7102.

[26] Shaffer, S., 1990, Regulatory Compliance With Nonlinear Penalties, ***Journal of Regulatory Economics***, 2: 99-103.

[27] Segerson, K. and T. Tietenberg, 1992, The Structure of Penalties in Environmental Enforcement: An Economic Analysis, ***Journal of Environmental Economics and Management***, 23: 179-200.

[28] SINA, 2005, The Gresham's Law in the One-shot Tableware (in Chinese), Downloaded from http://finance.sina.com.cn/roll/20051107/0040385961.shtml.

[29] Swierzbsinski, J. E., 1994, Guilty until Proven Innocent-Regulation with Costly and Limited Enforcement, ***Journal of Environmental Economics and Management***, 27: 127-146.

[30] Viscusi, W. K. and Zeckhauser, R., 1979, Optimal Standards with Incomplete Enforcement, ***Public Policy***, 27: 437-456.

[31] Xepapadeas, A. P., 1991, Environmental Policy under Imperfect Information: Incentive and Moral Hazard, ***Journal of Environmental Economics and Managemen***t, 20: 113-126.

[32] Zejian On Line, 2005, Dismantling Used Stuffs: Recycling or Environment-Exhausting? (in Chinese), Downloaded from http://www.zjol.com.cn/system/2005/07/27/0_20050727.shtml.

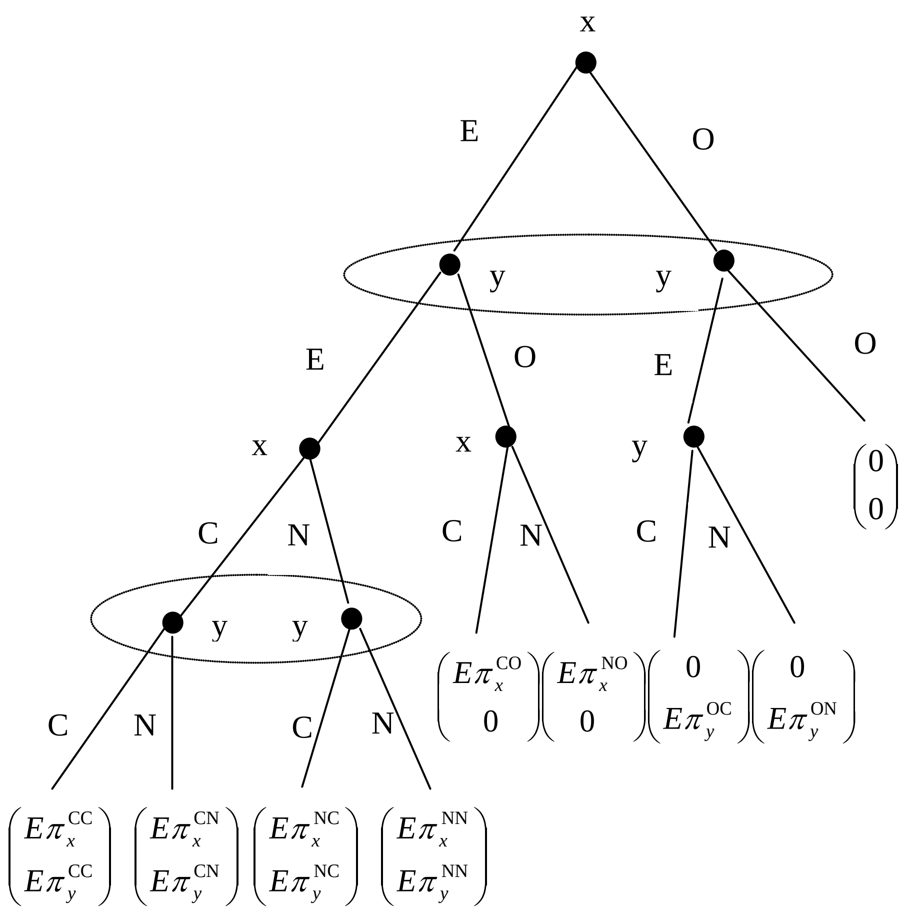


Figure 1. The Extensive Form of the Basic Model

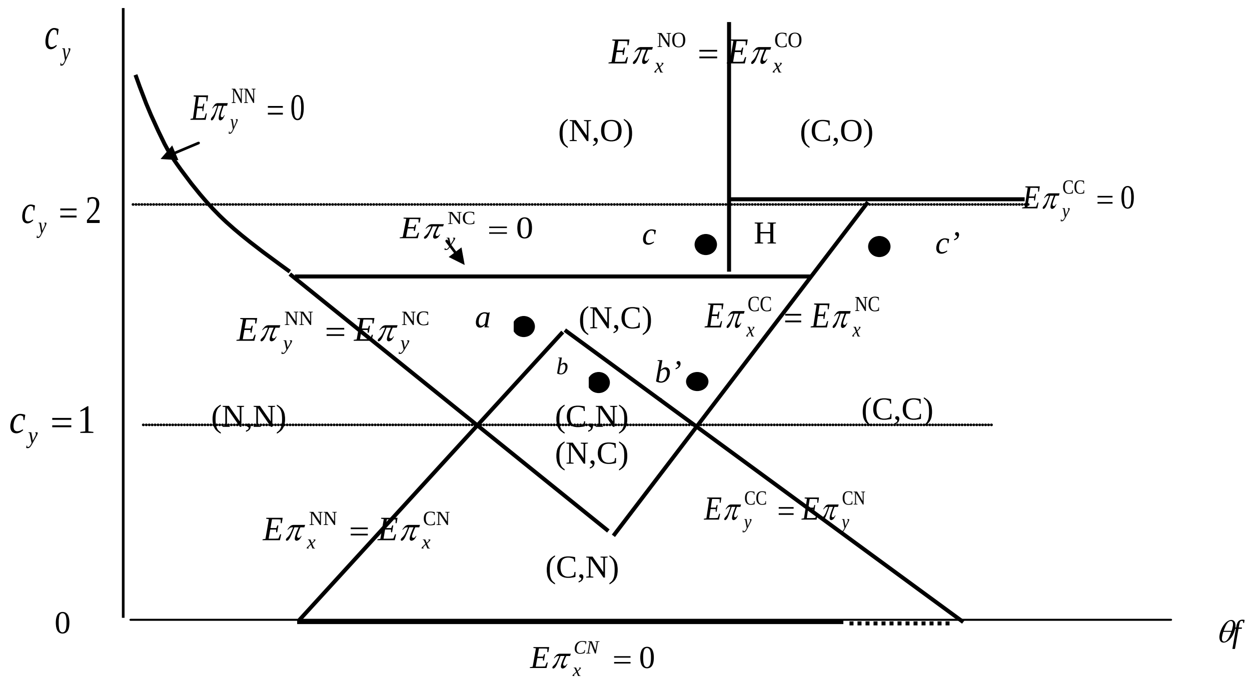


Figure 2. Nash Equilibrium Regimes for a Loose Environmental Standard
(*a*=4, *b*=1, c_x=1, and *s*=1)

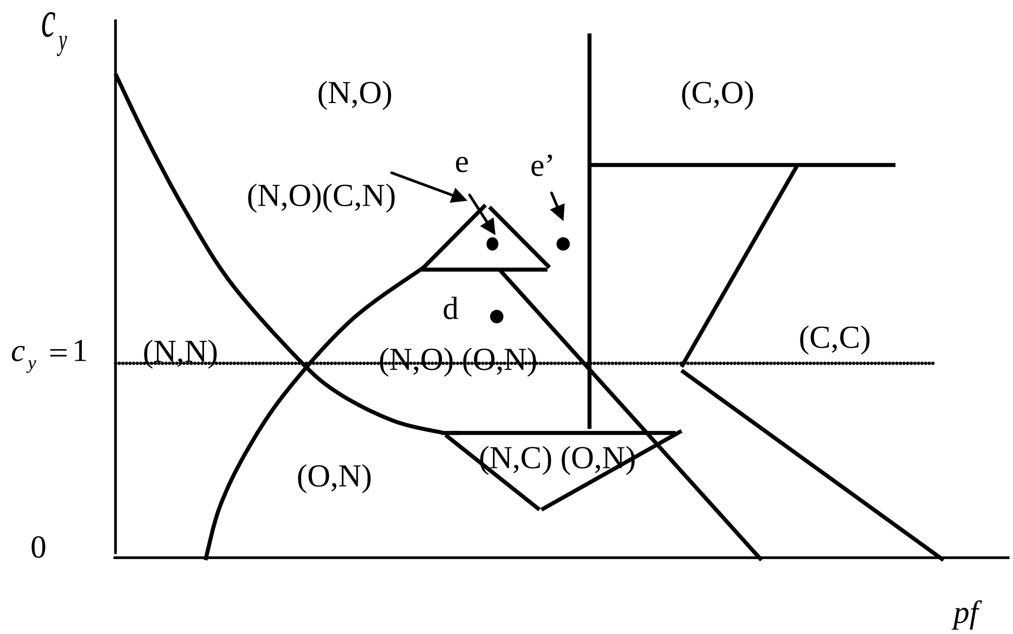


Figure 3. Nash Equilibrium Regimes for a Rigorous Environmental Standard
(a=4, b=1, c_x=1, and s=1.7)

Emissions Abatement in a Production Economy: Cost-minimization versus Investment-consumption Optimization

Lie-Jane Kao
Department of Finance and Banking, KaiNan University, Taoyuan,Taiwan

An alternative mechanism of emission allowance trading system, based on the production economy by Cox, Ingersoll, and Ross (1985a, b), is proposed in this study. Under the proposed mechanism, individuals can invest their wealth in the abatement technologies directly or indirectly through firms. In addition, there exists a market for risk-free borrowing/lending and a market for a zero-net-supply contingent claim that guarantees payoffs of emission allowances on a specific date in the future. The mechanism, designed to avoid the “hot air” trading problem encountered in a cap-and-trade system, improves the efficiencies of an allowance trading system in three respects: 1) All the resources/wealth within the economy are invested in the physical emission abatement technologies, 2) The more “business-as-usual” emission allowances are in demand, the more reductions are “produced”, 3) The risk of changing demands in emission allowances is hedged via the zero-net-supply contingent claim of emission allowances.

Keyword. Emission allowance, Production economy, Abatement technology, Zero-net-supply, Contingent claim, Hot air trading, Cap-and-trade system.

1. Introduction

Countries with commitments to reduce greenhouse gas (GHG) emissions, i.e., the Annex 1 countries, must meet their emission targets of 5.2% reduction of their 1990 level in the period 2008-2012 under the Kyoto Protocol. These targets are expressed as levels of "allowed" emissions over the commitment period, and are further divided into "assigned amount units" **(AAUs)** with one unit of **AAU** corresponds to the right to emit one ton of GHG into the atmosphere. To achieve these targets efficiently, emission reduction shall take place wherever it is the cheapest. Based on this fact, the Kyoto Protocol, while maintaining domestic mitigation efforts, promotes emissions trading that allows Annex I countries to trade emission reduction units that are above or below their emission targets in supplement to domestic actions.

On this account, the need for a trading system is obvious. Currently, the world's largest GHG emission trading system, European initiative EU Emission Trading Scheme (EU ETS) launched by the Directive 2003/87/EC of the European Parliament, has entered into operation in 2005. Under the EU ETS, carbon emission allowances (EUAs) are yearly allocated by National Allocation Plan (NAP) of responsible governments to more than 12,000 mandatory participating installations. Installations with surplus EUAs are allowed to sell from the market. On the other hand, installations with emissions exceeding their allocated EUAs will either abate some of their emissions or buy the EUAs from the market. If the participating installations fail to comply, penalties will be imposed on them. To ease the burden upon the installations, the "Linking Directive" of EU ETS allows installations to use certain amounts of emission reduction credits from abatement projects of the other two mechanisms of Kyoto Protocol, namely, the Joint implementation (JI) and Clean

Development Mechanism (CDM), to cover their emissions. One ERU (or CER) represents one ton of CO_2 emissions reduction.

Nevertheless, the establishment of emission trading system requires deliberate design, otherwise it may result in the so called "carbon bubble". For example, countries like Russia might have tremendous surplus in its assigned amount of emission due to economic decline instead of any abatement efforts. In case Russia sells this surplus, "hot air" trading takes place and no emissions have been reduced at all (Victor et al., 1998; Woerdman, 2005). The problem of "hot air" trading by Russia stems from the fact that the emission targets and therefore the assigned amount of emission allowances under Kyoto protocol were based on 1990's emission level. As emissions in Russia dropped dramatically as a result of economic declines after the 1990s, the tremendous amount of surplus emission allowances that are assigned free-of-charge thus becomes the potential "carbon bubble".

Taking the possible "hot air" trading problem into account, emission reductions via a cap-and-trade system like EU ETS might not be as efficient as expected. As the success of a cap-and-trade system relies heavily on the emission trading market's scarcity induced by the current demand and supply, the allocations of free-of-charge assigned amount of emissions, or AAUs, play a central role in a cap-and-trade system. Due to the uncertainty in the demand of emission allowances year by year, excess supply of AAUs could become the major source of risk in a cap-and-trade system. On May 2nd, 2006, CO_2 prices in the EU ETS nearly halved after Belgium, the Czech Republic, Estonia, France, the Netherlands and Spain reported lower-than-expected CO_2 emissions in 2005 (Paolella et al., 2008). The spot price closed at €10.90 per ton on Powernext on that day, compared with a price of just under €30 per ton at the close of trading on April 24, 2006. The significant drop of CO_2 prices due to excess supply of free-of-charge AAUs only reduces the incentives of abatement actions, and may undermine the commitments to achieve global climate stabilization.

This study proposes an alternative trading mechanism other than the cap-and-trade system like EU ETS for emission reductions. The proposed mechanism is based on the observations that abatement projects may not necessarily result in net costs, rather it may bring about net benefits (Jackson, 1995). These benefits may be due to the adoption of more efficient environmental technologies, the growth of energy-saving technology innovations, and production expansions. Ekins (1995) points out that a moderate abatement of CO_2 emission will improve unemployment and prior tax distortions, recycle revenue, and bring the secondary benefits of reducing CO_2 emissions. It is also expected that investors can increase their export potential of advanced pollution control technologies through JI or CDM (Jones, 1993; Woerdman, 2000). This implies that investment decisions in emission abatement projects yield not only emission savings but also potentially generated revenues that can be used to (partially) pay back the investments. Therefore, emission reduction via abatement technologies is not just a problem of cost minimization; rather it is a problem of profit expectation of investments in abatement technologies.

On this ground, the proposed mechanism considers a framework for abatement technology investments and emission allowance consumptions in a production economy developed by Cox, Ingersoll, and Ross (1985a, b). The framework is characterized by a changing investment environment that depends on the abatement technologies innovations, which in turn depends on the “business-as-usual” demand for the emission allowances. Individuals within the economy can invest their wealth in the abatement technologies directly or indirectly through firms. In addition, it is assumed that there exists a market for risk-free borrowing/lending and a market for a zero-net-supply contingent claim that guarantees payoffs in terms of emission allowances on a specific date in the future. Under such framework, the proposed mechanism greatly improves the efficiency of an allowances' trading system in three folds. First, all the resources/wealth are allocated among the "production" of emission reduction, that is, no resources/wealth are allocated on the free-of-charge assigned amount of emission allowances, therefore, the occurrences of the so called "carbon" bubbles can be avoided. Second, the return rates of the abatement technologies increase as the demand for the allowances increases, that is, the more emissions generated, the more reductions produced. Finally, as the price of the zero-coupon "bond" decreases when the demand for the allowances increases, the risk of changing demands of emission allowances can be perfectly hedged through the zero-coupon "bond".

The outline of the paper is as follows. In Section 2, the mechanism of a cap-and-trade system is considered. The mechanism of an allowance trading system via production is given in Section 3. Section 4 considers the production economy by Cox, Ingersoll, and Ross (1985ab). A numerical analysis is given in Section 5. Section 6 concludes.

2. Emission reduction via Cap-and-trade

The design of a cap-and-trade system, one of the main concerns for regulatory authority is to fulfill environmental targets and, on the other hand, to achieve these targets at lowest costs for the consumers. The two objectives can be attained by taking into considerations of the differentiated marginal abatement costs among different regions as well as different sectors. Countries or installations with higher marginal abatement costs can upload their obligation for emission reduction commitment by purchasing emission allowances from parties with lower marginal abatement costs. By making optimal use of these marginal abatement cost differences, it is hoped that the overall abatement costs of GHG emissions can be greatly reduced (Richels et al., 1996; Seifert, 2009).

In literature, the prices of emission allowances in the presence of emission targets are derived via different approaches. For example, by considering the amounts of realized emissions and emission allowances purchased/sold as two control variables, Rubin (1996) shows that the system's joint cost is minimized when each firm individually minimizes its overall costs of abatement and emission allowances' purchased expenses. In addition, the emission allowance's price equals to the marginal abatement cost and grows at the riskless interest rate when there are no bounds imposed on the amounts of emission allowances purchased or sold. Based on the assumption that allowance's price equals to the marginal abatement cost, Seifert et al.(2009) derive emission allowance's price by minimizing the total costs of abatement and non-compliance penalties with the abatement rate as a control variable. In Fehr et al. (2005), on the other hand, it was shown that an optimal reduction policy that minimizes the global abatement and penalty costs exists and if the optimal reduction policy is followed, the equilibrium allowance's price equals to the penalty per ton of emission times the probability that the actual emissions exceeding the targets.

Both Seifert et al.(2008) and Fehr et al. (2005) suggest that if the business-as-usual emission demand is below the emission target, then the allowance's price equals to zero. Under such development, no efforts on the emission abatements will be made, and when other factors like excess supply of allowances affect the allowance's price, the efficiencies of the cap-and-trade system to reduce emission are of now in questions. The collapse of the price on May 2nd, 2006 due to excess supply of the EUAs provides an example that the allowance's prices do not solely depend on the marginal abatement cost. This observation calls for an alternative mechanism other than cap-and-trade system for GHG emission reduction. In the following, an alternative mechanism that is designed based on the investment-consumption prospect is proposed.

3. Emission Reduction via Production

In addition to a emission trading system (ET), the Kyoto protocol contains the other two mechanisms, i.e., the Joint implementation (JI), and Clean Development Mechanism (CDM) that are designed to support Annex I members to meet their targets as follows:

- Emission Trading System (ET), exchange AAUs from other Annex I members.
- Joint Implementation projects (JI), which allows industrialized countries with a greenhouse gas reduction commitment (called Annex 1 countries) to invest in ventures that reduce emissions in Annex 1 countries where reductions are cheaper, and then applying the credit for those reductions towards their commitment goal, produces Emissions Reduction Units (ERUs).
- Clean Development Mechanism (CDM), which allows Annex 1 countries to invest in developing countries as an alternative to more expensive emission reductions in Annex 1 countries, produces Certified Emission Reductions (CERs).

According to Woerdman (2000), JI provides about 2 times as cheap as the averaged marginal abatement cost within the Annex I countries. Similarly, as the marginal abatement costs are cheaper in the non-Annex I countries, one can expect that CDM provides the cheapest emission reduction credits than JI or ET (Woerdman, 2000). Making use of its competitive marginal abatement cost, the point here is that any GHG abatement project, by its nature, yields a payoff depending on the market demands for emission allowances. In another word, investments in emission abatement projects should be considered as “carbon assets”, rather than “liabilities”.

In this concept, instead of a cap-and-trade system, this study considers a system under which emission allowances are "produced" only via the *n* abatement technologies and nothing is generated without any physical abatement of GHG emission. As the main concern for a cap-and-trade system is the excess supply of free-of-charge emission allowances and no emissions have been reduced at all, the proposed mechanism is designed in a way that emission allowances are granted only via physical "production" of emission reductions. It is assumed here that one unit of the emission allowance corresponds to β ton of GHG emission abatement, where $0 \le \beta \le 1$. Under such production economy, the output of the system are either allowances consumed by individuals to cover their GHG emissions, or costlessly transformed into capitals that can be used to re-invest in the *n* abatement technologies or to trade in emission allowances. Emission allowance trading takes place continuously via allowance "bonds" that guarantee deliveries of emission allowances on the maturity dates. There is also a market where individuals can borrow or lend capitals at a risk-free interest rate *r* (Cox, Ingersoll, and Ross, 1985a).

In the proposed mechanism, production opportunities depend on the "business-as-usual" demand for the emission allowances, which is changing randomly over time. As the demand for the emission allowances increases, the return rates of the *n* abatement technologies increase, on the other hand, the price of a zero-coupon allowance bond that pays one unit of emission allowance when it matures decreases. For a given demand of emission allowances, equilibrium price of the zero-coupon allowance bond and risk-free interest rate can be attained under which all capitals and wealth within the system are invested in the abatement technologies, while the net supply of the allowance "bonds" is zero.

The problem now becomes how to allocate individuals' wealth among consumptions and the (*n*+2) investment opportunities including the *n* risky abatement technologies, the contingent claim for emission allowances, and risk-free borrowing and lending. By adjusting the price of the zero-coupon "bond" of allowances and risk-free interest rate, in equilibrium all the resources/wealth within the economy will be invested in the *n* abatement technologies. In another word, investment opportunities other than the *n* abatement technologies have zero net supply. According to Cox, Ingersoll, and Ross (1985a,b), the equilibrium price of the zero-coupon "bond" and risk-free interest rate will depend on the "business-as-usual" demand for the emission allowances. Given the prerequisite of market equilibrium, individuals choose their optimal consumption levels and proportions of wealth to be invested in the (*n*+2) investment opportunities so as to maximize their lifetime utilities of consumptions. Under such development, emission reduction via abatement projects becomes an investment-allocation and utility-maximization problem instead of a cost- minimization problem.

4. CIR's production Economy

The continuous-time optimal consumption and portfolio choice problem was first formulated by Merton (1969, 1971, 1972). In Merton's model, asset prices are subject to continuous random changes due to changing production opportunities available to the economy in the future. Under such changing environment, an individual is allowed to reallocate his investment portfolio continuously so as to maximize his expected lifetime utility of future consumptions.

Later, Cox, Ingersoll, and Ross (CIR) (1985a, 1985b) proposed a production economy where a single capital-consumption good is produced by *n* different technologies that are in perfectly elastic supply, i.e., output from the *n* technologies could be reinvested as well as consumed. As in Merton (1972), the framework of Cox et al. (1985a, 1985b) includes uncertain production opportunities characterized by a $k\times 1$ state variable $\boldsymbol{x}(t)=(x_1(t),\dots, x_k(t))'$ that is changing randomly over time with its l^{th} item satisfies

$$\mathrm{d}x_l(t)=a_l(\boldsymbol{x}, t)\mathrm{d}t+b_l(\boldsymbol{x}, t)'\mathrm{d}Y_l(t), \qquad l=1,..., k$$

where $a_l(\boldsymbol{x}, t)$ and $b_l(\boldsymbol{x}, t)$ might depend on the state variables $\boldsymbol{x}(t)$, $Y_1(t),\dots, Y_k(t)$ are k Brownian motions. For simplicity, it is assumed there is only one state variable, i.e. k=1. Here the one-dimensional state variable x represents the rate of "business-as-usual" demand for emission allowances, which follows a nonnegative mean-reverting process

$$\mathrm{d}x(t)=\{a_0-a_1x(t)\}\mathrm{d}t+ b\sqrt{x(t)}\,\mathrm{d}Y(t) \tag{1}$$

where $a_0>0$, $a_1>0$, and $b>0$. The state variables $x(t)$ will be contemporaneously correlated with the instantaneous return rates of the n technologies governed by a set of n stochastic processes

$$\mathrm{d}S_i(t)/S_i(t)=\mu_i x\mathrm{d}t+\sigma_i\sqrt{x}\,\mathrm{d}Z_i(t), \qquad i=1,..., n \tag{2}$$

where S_i is the amount of the capital-consumption good invested in the i^{th} technology, $\mu_1,\dots, \mu_n$ and $\sigma_1,\dots, \sigma_n$ are constants. In (2), the expected instantaneous return rates and variances of the n technologies are proportional to the state variable $x(t)$, the "business-as-usual" demand of emission allowances at time t. The n Brownian motions $Z_1(t),\dots, Z_n(t)$ represent n sources of uncertainty associated with the n technologies, where $(\sigma_i\sqrt{x}\,\mathrm{d}Z_i)(\sigma_j\sqrt{x}\,\mathrm{d}Z_j)=\sigma_{ij}x\mathrm{d}t$ and $(b\sqrt{x}\,\mathrm{d}Y)(\sigma_i\sqrt{x}\,\mathrm{d}Z_i)=\phi_i x\mathrm{d}t$. Let $\Omega=[\sigma_{ij}]_{1\le i,\, j\le n}$, $\boldsymbol{\mu}=(\mu_1,\dots, \mu_n)'$, and $\boldsymbol{\phi}=(\phi_1,\dots, \phi_n)'$.

As there are $(n+1)$ sources of uncertainties that drive the dynamics of the system, to hedge these $(n+1)$ sources of uncertainties, an investment opportunities basis will be formed including the n technologies and a contingent claim (Cox, Ingersoll, and Ross, 1985a). In addition to the $(n+1)$ risky investment, a risk-free investment opportunity of borrowing and lending also exists in the market. Suppose individuals have identical preferences regarding the consumption of this capital-consumption good and identical initial wealth, one objective of CIR's production economy is to decide the amount of the wealth to consume versus to save, and to allocate the saved amount to invest between the *n* different technologies so as to maximize their lifetime time-separable utility. Specifically, one chooses the optimal consumptions *C* and portfolio weights $w_1,\ldots, w_n$ that maximize

$$\max_{C_s, w_1, \ldots, w_n} E_t\left[\int_t^T U(C_s, t)ds + B\left(W_T, T\right)\right] \tag{3}$$

where C_s represents the consumption rate per unit time at time *s*, $w_1,\ldots, w_n$ are proportions of the total wealth

$$W = \sum_{i=1}^{n} S_i(t)$$

invested in the *n* technologies, respectively, W_T is the final wealth at time *T*, *U* and B are logarithm utility and bequest functions of the forms

$$U(C, t) = e^{-\rho t} \ln(C)$$

$$B(W, T) = e^{-\rho T} \ln(W)$$

that are increasing, strictly concave, and twice differentiable. In market equilibrium defined by Cox et al. (1985a, 1985b), investment opportunities other than the *n* technologies have zero net supply. This amounts to

$$\sum_{i=1}^{n} w_i = 1 \tag{4}$$

where w_i is the proportion of the total wealth invested in the i^{th} technology. Subject to this constraint, the dynamics of the total wealth *W* can be written down as

$$dW = W\left(\sum_{i=1}^{n} w_i\, \mu_i(x,t)\right)dt - C dt + W\left(\sum_{i=1}^{n} w_i\, \sigma_i(x,t)\right)' \boldsymbol{dZ} \tag{5}$$

At equilibrium, the optimal consumption rate C^* is given by

$$C_t^* = \frac{\rho}{1-(1-\rho)e^{-\rho(T-t)}} W_t$$

The risk-free interest rate r satisfies

$$dr = a_1(\pi - r)dt + \nu\sqrt{r}\, dY$$

where $\alpha=(\mathbf{1}'\Omega^{-1}\mu\text{-}\mathbf{1})/\mathbf{1}'\Omega^{-1}\mathbf{1}$, $\pi=\alpha a_0/a_1$, $\nu= b\sqrt{\alpha}$, $\mathbf{1}$ is a $n\times1$ vector with all elements ones. The price of the zero-coupon allowance bond that matures at time $T>t$ follows from Cox et al. (1985a, 1985b) as

$$P(t, Y)=\exp\{A(t, T)\text{-}B(t, T)r(t)\} \qquad (6)$$

where

$$A(t, T)=\frac{2a_1\pi}{\nu^2} log\left(\frac{2\gamma e^{(\gamma+a_1)(T-t)/2}}{(\gamma+a_1)\left(e^{\gamma(T-t)}-1\right)+2\gamma}\right)$$

$$\gamma = \sqrt{a_1^2 + 2\nu^2}$$

$$B(t, T)= \frac{2e^{\gamma(T-t)}-2}{(\gamma+a_1)\left(e^{\gamma(T-t)}-1\right)+2\gamma}$$

The optimal portfolio weights $\boldsymbol{w}^*=\{ w_1^*, \ldots, w_n^*\}$ that is subject to the constraint (4) are

5. Numerical Example

In this Section, an example is given to illustrate the proposed mechanism with parameters chosen to reflect some stylized facts in the EU ETS for the 3 years 2005–2007 (Seifert et al., 2008). Suppose the timescale is on a daily basis, then the timespan T=365*3=1085. From Seifert et al. (2008), EUAs in the magnitude of 6 billion tons of CO_2 are allocated during 2005–2007, while the expected amount of emission is 6.24 billion tons of CO_2, the expected “business-as-usual” demand for emission allowances per day is

$$(6.24\text{-}6)\times 10^9 \text{ tons } /(3\times 365)=2.19\times 10^5 \text{ tons /day}$$

As a_0/a_1 represents the long-term mean of daily emission allowance demand, let $a_0/a_1=2.19\times 10^5$. The volatility of daily emission allowance demand is chosen based on the annual volatility of $500/\sqrt{3}$ from Seifert et al. (2008) to induce a daily volatility of 15.10 tons. This results in the parameter value b=0.0322.

Suppose there are 10 different abatement technologies (n=10) with coefficients $\mu=(\mu_1,\ldots,\mu_{10})'= 10^{-7}\times(0.1\ 1\ 2\ 3\ 4\ 5\ 6\ 7\ 8\ 9)$, and the coefficients $\sigma_1=\ldots=\sigma_n= 10^{-4}\times 2.137$.

6. Concluding Remark

This study provides a different mechanism for emission reduction other than the cap-and-trade system. The rationale behind the mechanism is that investments in emission abatement projects should be considered as "carbon assets", rather than "liabilities". Individuals in the system obtain their emission allowances via investments in abatement technologies instead of exchanges for the surplus of assigned emission allowances that are free-of-charges in a cap-and-trade system, in which the largest risk is the changing demand of emission allowances. By allowing for a zero-coupon bond that pays for one unit of emission allowance on a specified future date, the risk from changing demand can be hedged. Not only that, in equilibrium, all the resources within the economy will be invested among the abatement technologies

References

Benz, E., Truck, S. (2009). Modeling the price dynamics of CO_2 emission allowances. Energy Economics 31, 4–15.

Cox, J.C., J.E. Ingersoll, and S.A. Ross (1985a), An intertemporal general equilibrium model of asset prices, Econometrica, 53, 363-384.

Cox, J.C., J.E. Ingersoll, and S.A. Ross (1985b), A theory of term structure of interest rates, Econometrica, 53, 385-408.

Cox, J.C., and Huang, C.F. (1989), Optimal consumption and portfolio policies when asset prices follow a diffusion process, Journal of Economic Theory, 49,33-83.

Daskalakis, G., Markellos, R.N., 2008. Are the European carbon markets efficient? Review of Futures Markets 17, 103–128.

Daskalakis, G., Psychoyios, D., and Markellos, R.N. (2009). Modeling CO_2 emission allowance prices and derivatives: Evidence from the European trading scheme, Review of Futures Markets 17, 103–128.

Ekins, P. (1995), Rethinking the costs related to global warming: a survey of the issues, Environmental and Resources Economics 6: 231-277, 1995

Fehr, M., and Hinz, J. (2006). A Quantitative Approach to Carbon Price Risk Modeling, Working Paper, Institute for Operations Research, ETH Zentrum, Zu rich.

Harrison, J.M., and Kreps, D.M., (1979), Martingale and arbitrage in multiperiod securities markets, Journal of Economic Theory, 20, 381-408.

Jackson, T. (1995), 'Joint Implementation and Cost efficiency under the Framework Convention on Climate Change', Energy Policy, 23(2).

Lucas, R.E. (1978), Asset prices in an exchange economy, Econometrica, 46, 1429-1445.

Merton, R.C. (1969), Lifetime portfolio selection under uncertainty:The continuous time case, Review of Economics and Statistics, 51(3), 247-257.

Merton, R.C. (1971), Optimum consumption and portfolio rules in a continuous time model, Journal of Economic Theory, 3(4), 373-413.

Merton, R.C. (1972), An analytical derivation of the efficient portfolio frontier, Journal of Financial and Quantitative analysis, 7, 1851-1872.

Paolella, M.S., Taschini, L. (2008). An econometric analysis of emission trading allowances. Journal of Banking and Finance 32, 2022–2032.

Pliska, S. (1986), A stochastic calculus model of continuous time trading: Optimal portfolio, Mathematics of Operation Research, 11, 371-382.

Rubin, J.D., 1996. A model of intertemporal emissions trading, banking, and borrowing. Journal of Environmental Economics and Management 31, 269–286.

Seifert, J., Uhrig-Homburg, M., Wagner, M. (2008). Dynamic behavior of CO2 spot prices. Journal of Environmental Economics and Management 56, 180–194.

Uhrig-Homburg, M., Wagner, M., 2008. Derivative instruments in the EU emissions trading

scheme: An early market perspective. Energy and Environment 19, 635–655.
Wachter, J.A. (2002), Portfolio and consumption decisions under mean-reverting returns: An exact solution for complete market, Journal of Financial and Quantitative analysis, 37(1), 63-91.
Woerdman, E. (2000), 'Implementing the Kyoto protocol: why JI and CDM show more promise than international emissions trading', *Energy Policy* 28, 29-38
Woerdman, E. (2005), Hot Air Trading under the Kyoto Protocol: An Environmental Problem or Not? *European Environmental Law Review* 14 (3), pp. 71-77.

Do Environmental Regulations Increase Bilateral Trade Flows?

Tetsuya Tsurumi [1], Shunsuke Managi [2*], and Akira Hibiki [3]

[1] Graduate School of Frontier Sciences
The University of Tokyo
5-1-5, Kashiwano-ha, Kashiwa city, Chiba, 277-8561, Japan

[2] Graduate School of Environmental Studies,
Tohoku University
6-6-20 Aramaki-Aza Aoba, Aoba-Ku, Sendai, Miyagi 980-8579, Japan
Tel. 81- 45-339-3751/ Fax: 81- 45-339-3707

[3] Social Environmental Systems Division, National Institute for Environmental Studies
16-2, Onogawa, Tsukuba-City, Ibaraki, 305-8506, Japan
Tel. 81- 29-850-2510

Do Environmental Regulations Increase Bilateral Trade Flows?

Abstract

Stringent environmental regulations are generally thought to harm export flows. This argument is crucial in determining policy recommendations for environmental preservation and international competitiveness. Using bilateral trade data, we examine the relationship between trade flows and various kinds of environmental stringency indices. Our results imply that stringency could have beneficial effects on trade flows.

Keywords: Environmental regulation, International competitiveness, Trade and environment, Gravity model

1 Introduction

Strengthening environmental regulations affects not only international competitiveness of firms but also the leakage of pollutants through change in trade flow. Thus, the effect of regulations on trade flows is crucial in policy debate of environmental regulations and has been explored in the last decade (e.g., Copeland and Taylor, 2004).

Among policy makers and academic researchers, there is a general belief that more stringent environmental regulations require abatement costs and therefore increase the production costs, which results in a weaker competitiveness of the industry (Pethig, 1976; Mcguire, 1982; Jenkins, 1998). Thus some studies find that stricter regulations reduce trade flow (e.g., van Beers and van den Bergh, 1997). However, the other studies find the opposite results (Constantini and Crespi, 2008).

There are several reasons which are likely to lead to such inconclusive results: (1) estimation methodologies, (2) lack in the theoretical background and (3) choice of the variables used for stringency of environmental regulations. Firstly, the previous studies do not necessarily apply appropriate econometric method. Many studies do not address the endogeneity problem of the policy variable in an appropriate way. Secondly, many studies, which focused on the bilateral trade flow, do not consider the theoretical framework, Hechscher-Ohlin-Vanek (HOV) model, in the specification sufficiently. On the other hand, there are some studies based on the theoretical framework using HOV model but they do not focus on the bilateral trade flow. Thirdly, the previous studies do not take the various aspects of regulations into consideration. The energy intensity, abatement cost or policy index which is constructed using a survey index is used as a proxy of the stringency of regulations in previous studies. The energy intensity is likely to capture the stringency of regulations which contribute to the reduction of air pollutions, especially the improvement of the energy saving rather than that of regulations for water pollution, waste management among others. On the other hand, the abatement cost is likely to capture the stringency of all types of environmental regulations. Policy index includes not only how stringent the environmental legislation is, but also how long the legislation existed, how widespread the policy is among industries, or the degree of environmental awareness citizens have (Xu, 2000). Thus, in order to capture various aspects of regulations and to identify the effect of difference in the aspects, it is important to use those variables simultaneously rather than to use the single one.

The purpose of this article is to improve the previous studies by employing more appropriate econometric method, applying the framework of HOV model to bilateral trade flow and using several policy variables. The key contribution is expected to capture the different aspects of regulations and to contribute to organize the results by addressing the shortcoming of the previous studies.

Next section presents a background. Section 3 provides our model and section 4 shows empirical results. The last section presents a summary of research findings and discussions.

2 Literature Review

Previous studies are largely divided into two groups. One is based on Heckscher-Ohlin-Vanek (HOV) model and the other is based on Gravity model. Table 1 summarizes the literature.

(Insert Table 1)

(Studies following Heckscher-Ohlin-Vanek model)

The previous studies take the framework following HOV model into consideration in their analysis and explore the effect of regulations on total trade flow of a country (e.g., Tobey, 1990; Cole and Elliott, 2003; Babool and Reed, 2009). They use one of three types of survey data as a proxy of environmental stringency: a survey conducted at the United Nations Conference on Trade and Development (UNCTAD) in 1976, that conducted at the United Nations Conference on Environment and Development (UNCED) in 1992, and that conducted at the Center for International Earth Science Information Network (CIESIN) in 2002 and 2005.

Tobey (1990) explores determinants of total trade flow by ordinary least square (OLS) using the index based on a survey conducted at UNCTAD in 1976[1] and the other cross-sectional data (23 countries of both developed and developing countries). He finds no statistically significant relation between the regulations and trade flows. Cole and Elliott (2003) uses the other policy indices: the energy intensity as a proxy of regulations and the indices[2] which are developed by Dasgupta et al.

[1] This index is measured on a scale from one (tolerant) to seven (strict).

[2] The index developed by Dasgupta et al. and that developed by Eliste and Fedrikson are named as DMRW index and EF index for short hereafter. Dasgupta et al. (2001) have randomly selected 31

(2001) and Eliste and Fredriksson (2002) using 1992 UNCED survey data.[3] They consider the potential endogeneity of environmental regulations using instrumental variables (IV) and find no statistically significant results. Although they extend Tobey's (1990) analysis by addressing the potential endogenous problem of environmental regulations using IV and a larger dataset, they find no significant results. Babool and Reed (2010) estimate fixed effect model using panel data for 13 industries and the policy index constructed using information of the CIESIN for 2002 and 2005[4], and find that in most manufacturing industries more stringent environmental regulations have statistically significant negative effects on international competitiveness, while they find statistically significant positive relationships in several industries such as paper products, wood products, and textile products.[5]

These previous studies have an advantage in following the theoretical framework of HOV model but have disadvantage in focusing on total trade flow but not the bilateral trade flow. Therefore, they did not consider the possibilities that the effect of differences in regulations between countries on trade flow is likely to cancel out. This might be because previous studies are more likely to find no evidence on relation between stringency of regulations and trade flow.

(Studies by Gravity model)

The other studies explore how regulations affect bilateral trade flow using gravity model. van Beers and van den Bergh (1997) find that the environmental stringency has a significant negative effect on international competitiveness, using

---

UNCED reports from the total of 145. The reports are reasonably comparative since the United Nations imposed a standard reporting format (see Dasgupta et al., 2001 for more details). Eliste and Fredriksson (2002) focused on the agricultural sectors and extended country coverage to 62 countries using the same methodology as Dasgupta et al. (2001). Both index covers developed and developing countries but it should be noted that, while DMRW index includes the information on formal sanction for misreporting emission, EF index does not.

3 The survey assessment uses 25 questions to categorize the state of: (1) environmental awareness; (2) scope of policies adopted; (3) scope of legislation enacted; (4) control mechanisms in place; and (5) the degree of success in implementation. For each report, 25 questions are answered for 20 elements, and therefore 500 assessment scores are developed for each country. Assessment score is 0, 1, and 2. Therefore each country's score ranges from 0 to 1000. The more stringent the assessment is evaluated, more the score is.

4 The index for 2002 is calculated from eight variables from the Environmental Sustainability Index (ESI) report for 2002 and that for 2005 is calculated from twelve variables from the ESI report for 2005 (see Babool and Reed, 2010 for more information).

5 In contrast, Cole and Elliott (2003) obtain statistically significant result applying the intra-industry trade type analysis. They find that environmental regulations are determinants of the share of inter-industry trade. They mention that the reason why their results from HOV model is different from those from the inter-industry trade analysis is that the latter concentrates on bilateral trade and the shares of intra- and inter-industry trade in total trade. We do not report studies applying inter-industry trade type analysis because it is beyond the scope of our study.

cross-section data of OECD countries in 1992 and two policy indices; their own stringency index and energy intensity[6]. Harris et al. (2002) use a three-way fixed–effects model which allows for importing country, exporting country, and time-specific effect. Using energy intensity as a policy variable of 24 OECD countries over 1990-1996, they find no relationship between stringency and trade flows. It should be noted that both van Beers and van den Bergh (1997) and Harris et al. (2002) do not address the endogeneity problem of regulation variables. On the other hand, Jug and Mirza (2005) use 12 European Union (EU) countries' abatement costs, i.e., total current expenditure (CURE), provided by Eurostat to examine the relationship between relative stringency and export flows by addressing the endogeneity problem of a regulation variable. They find statistically significant negative effects on international competitiveness. The other studies obtain the opposite finding, that is, environmental regulations stimulate trade flow and result in enhancement of international competitiveness (see Xu, 2000; Constantini and Crespi, 2008)

These studies have an advantage in analyzing the bilateral trade flow but have disadvantage in not considering capital-labor ratio, which should be used under the theoretical framework following HOV model, though some previous studies might use GDP per capita as a proxy of capital-labor ratio. In addition, the possibility of endogeneity problem on regulation is not addressed appropriately in some studies, which is likely to affect estimation results.

(Characteristics of variables of environmental regulations)

As has already been explained, previous studies apply three different variables as proxies of environmental regulations: energy intensity, abatement costs, and policy indices.

Studies using energy intensity do not obtained robust results. When the endogeneity of stringency or fixed effects is taken into consideration, the estimation results become statistically insignificant (e.g., Harris et al., 2002; Cole and Elliott, 2003). In contrast, studies using abatement costs find that there is a possibility that environmental regulations have a negative effect on aggregate trade flows (e.g., Jug and Mirza, 2005), although environmental regulations might have a positive effect on trade

[6] This index is constructed from seven variables. These are protected areas as a percent of national territory in 1990, market share of unleaded petrol in 1990, recycling rate of paper in 1990, recycling rate of glass in 1990, percentage of population connected to sewage treatment plant in 1991, level of energy intensity in 1980, and change of energy intensity 1980-1991.

flows in energy industry (e.g., Costantini and Crespi, 2008). Finally, in the case of studies using policy indices, the results depend on used policy index.

The findings are inconclusive partly because the previous studies do not take the various aspects of regulations into consideration. The energy intensity is likely to capture the stringency of regulations which contribute to the reduction of air pollutions, especially the improvement of the energy saving rather than that of regulations for water pollution, waste management among others. The abatement cost is likely to capture the stringency of all types of environmental regulations. Policy index includes not only how stringent the environmental legislation is, but also how long the legislation existed, how widespread the policy is among industries, or the degree of environmental awareness citizens have (Xu, 2000). Thus, in order to capture various aspects of regulations and to identify the effect of difference in the aspects, it could be important to use those variables simultaneously rather than to use the single one.

3 Empirical Strategy

3.1 Basic Model

As discussed in section 2, there are some problems to be addressed both in the previous studies employing the framework following HOV model and those employing gravity model, respectively. The former studies do not consider cases that the effect of differences in environmental regulation stringency on trade flows between countries may cancel out as multilateral trade flows are an aggregate of bilateral trade. On the other hand, the latter ones face a criticism that usual gravity model does not consider factor-endowment, and, thus, comparative advantage following HOV model.

We address these issues by applying the generalized gravity model proposed by Bergstrand (1989). This model incorporates factor-endowment factors in the spirit of Heckscher-Ohlin and taste variables in the spirit of Linder into the basic gravity equation (Bergstrand, 1989). Following the generalized gravity model by Bergstrand (1989), we apply a following gravity model:

$$\begin{aligned}\ln Exp_{ij} &= \alpha + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln\left(K/L\right)_i + \beta_4 \ln GDPPC_j \\ &+ \beta_5 \ln Dist_{ij} + \beta_6 Boarder_{ij} + \beta_7 Landlocked_{ij} + \beta_8 \ln Str_i + \beta_9 \ln Str_j + \beta_{10} RTA_{ij} + \varepsilon_{ij},\end{aligned} \quad (1)$$

where EXP_{ij}, GDP_i, GDP_j, $(K/L)_i$ and $GDPPC_j$ are denoted as bilateral export flows from country *i* to country *j*, exporter *i*'s real GDP, importer *j*'s real GDP, exporter *i*'s capital labor ratio and importer *j*'s per capita real GDP, respectively. In addition, $Dist_{ij}$, $Boarder_{ij}$, $Landlocked_{ij}$, Str_i, Str_j, RTA_{ij} and ε_{ij} are denoted as distance between country *i* and country *j*, a dummy variable which takes 1 if country *i* and *j* share a boarder and 0 otherwise, a dummy variable which takes 1 if one country is landlocked, 2 if both countries are landlocked, and 0 otherwise, stringency of environmental regulations in exporting country *i*, stringency of environmental regulations in importing country *j*, a dummy variable which takes 1 if *i* and *j* belong to the same regional trade agreement and 0 otherwise, and error term, respectively.

We expect that the coefficient of exporter's real GDP is positive, since his real GDP captures his output level. On the other hand, we expect that the coefficient of importer's real GDP is negative, since his larger income (real GDP) is likely to increases his import.

Capital-labor ratio is expected to capture the effect of factor endowment on the trade, suggested by HOV model.

The distance variable, the border variable, and the landlocked variable are used to represent transportation cost and it is expected that there is more trade between countries that is adjacent, with common borders, or with access to the sea. It is also expected that regional trade agreements would enhance trade flows among member countries.

The main interest in this study is the coefficients for stringency variables. The sign of stringency for export countries is expected to be negative which indicates that stringent environmental regulations have negative effects on international competitiveness. However, this sign would be positive, if strict environmental regulations sufficiently stimulate a development of technology and strengthen international competitiveness, the sign could be positive. On the other hand, the sign of stringency for importing countries could be positive or negative. This is because production in an importing country is reduced and import is increased because of higher cost due to stronger regulation. Or if stricter regulations strengthen international competitiveness in importing country because of technological development, export in exporting country could be decreased.

In this study, we first examine the basic model of bilateral trade flow using a single environmental regulation variable and explore how the regulations affect the flow by addressing the shortcoming in the previous studies. Then in order to take the different aspect of regulations as an extension of this basic model, we examine the model using multiple regulation variables and explore how the different regulation variables affect the trade flow in different way.

3.2 Data

In this study, several types of policy variables are used including the energy intensity, abatement costs, 1992 UNCED index and CIESIN index following previous studies. Energy intensity is calculated as energy use (kg of oil equivalent) divided by real GDP. Data on energy use (kg of oil equivalent) and real GDP (constant $) are obtained from *World Development Indicators* (WDI). We extend time span from 1990–1996 of Harris et al. (2002) to 1990-2003. We also extend sample countries from 24 OECD countries of Harris et al. (2002) to 104 countries including developing and developed countries.[7] We present list of countries in Appendix A.

Abatement cost index is calculated as abatement cost divided by GDP following Jug and Mirza (2005) and Costantini and Crespi (2008). The abatement cost is obtained from Eurostat. Time span in our study is extended from 1996-1999 of Jug and Mirza (2005) to 1996-2003.

Two types of 1992 UNCED index[8] is constructed following Dasgupta et al. (2001) and Eliste and Fredriksson (2002). Although Xu (2000) uses 20 out of 31 countries due to lack of bilateral trade data, we have 31 countries for the case of Dasgupta et al. (2001) and 60 for the case of Eliste and Fredriksson (2002). We extend sample countries by using more comprehensive bilateral trade data collected by Rose (2005).

With regard to CIESIN index, we use "WEFSTR for 2000" from the 2001 Environmental Sustainability Index (ESI), "WEFGOV for 2001" from the 2002 ESI, and "WEFGOV for 2003" from the 2005 ESI. These data are different from the indices[9]

---

[7] We exclude the countries in Middle East from our estimation sample, such as Qatar, United Arab Emirates, Bahrain, and Kuwait because these countries use extremely large quantity of energy and seem to cause heterogeneity. (See Figure 1)

[8] Eliste and Fredriksson (2002)'s measure of stringency of environmental regulations is an index for the agricultural sector as is explained in footnote 2. However, we consider it sufficiently reflects the stringency of all sectors. In fact, correlations of each sector's score in Eliste and Fredriksson (2002) are from 0.855 to 0.968.

[9] The decomposed indices are available for WEFSTR for 2000, WEFGOV for 2001, and WEFGOV for 2003. See detailed information in Appendix C.

used in Babool and Reed (2010), and better match to the strictness of environmental regulations. Table 2 shows the detail. We need to note that these indices include not only "strictness" of the regulations, but also "quality" of the regulations, such as "clarity and stability of regulations", "flexibility of regulations", "leadership of environmental policy", and "consistency of regulation enforcement".

(Insert Table 2)

Real GDP per capita tends to be correlated with the stringency of regulation as discussed in Managi et al (2009) because higher income induce higher demand for better environment. Therefore in order to confirm this relationship, we show the simple scatter plots concerning the relationship between these environmental stringency variables and GDP per capita in Figure 1. Although we are able to find positive correlations between them, there are large variances in our sample.

(Insert Figure 1)

We obtain bilateral export flow data from Direction of Trade Statistics developed by the International Monetary Fund (IMF). GDP and per capita GDP are from *WDI*. Distance, boarder dummy, landlocked dummy, and regional trade agreement dummy are from Rose dataset (see Rose, 2005; Rose and Spiegel, 2009). Capital-labor ratio is obtained from Extended Penn World Table 3.0.[10]

4 Results

4.1 Basic Model

As is explained at Appendix B, the endogeneity problem of regulation is not confirmed.[11] Thus we deal with regulation variables as exogenous variables in our study. Table 3 and Table 4 present our results. Models vary by the regulation variable (energy intensity, abatement cost, and policy indices developed by Dasgupta et al. (2001), Eliste and Fredriksson (2002), the 2001 ESI, the 2002 ESI, and the 2005 ESI).

---

[10] http://homepage.newschool.edu/~foleyd/epwt/

[11] Although we examine IV method, we are not able to find appropriate instrumental variables. In appendix B, we show the results of the under-identification test, weak-identification test, and over-identification test to consider whether our instrumental variables are appropriate.

(Insert Table 3 and 4)

Concerning the results of the models using energy intensity or abatement cost, to consider the lag of the effect of regulation on trade flow, we apply three types of specifications as are shown in (a)-(f). (a) and (d) use current environmental stringency variables, while (b) and (e) use one-year-lagged environmental stringency variables. (c) and (f) use two-year-lagged environmental stringency variables. We implement panel analysis for these models and fixed effect model is chosen as the result of Hausman test.

Concerning the results of the models using policy indices, to consider the lag of the effect of regulations on trade flow, we employ OLS estimation using three types of cross sectional data depending on the sample year as shown in the tables. It should be noted that we did not implement panel analysis using all samples, since each policy indices capture regulation status of only one specific year.

The coefficients of exporter and importer GDP in all specifications are significant with expected sign. This indicates that increase in output of exporting country and income of importing country increase trade flow from exporting country to importing country. The estimates for exporter capital labor ratio in Table 3 are positive and statistically significant. This implies that more capital intensive exporters are likely to export more and that they are likely to have trade surplus. On the other hand, in Table 4 the coefficient estimates for exporter capital labor ratio tend to be negative, which implies that more capital intensive exporters are likely to export less.

The estimates for distance are all negative and statistically significant in all specifications. The landlocked dummy variable has the expected sign and often significant. The estimates for regional trade agreement are positive and statistically significant in all specifications, which suggests that regional trade agreements enhance trade flows among member countries as is expected.

The coefficients for exporter stringency variables differ among used variables. First of all, concerning exporter energy intensity, we obtain statistically significant negative signs (except for specification (a)). This implies the positive effect of the environmental regulation on export flows. This result is inconsistent with Cole and

Elliott (2003) and Harris et al. (2002), which find that insignificant results.[12]

With regard to exporter abatement costs, we obtain statistically significant negative signs, which is consistent with Jug and Mirza (2005). This implies that there is a possibility that stricter regulations have negative effect on export flows.

Concerning the exporter policy indices (from specification (g) to (s)), most of the coefficient are positive and statistically significant. This is consistent with Xu (2000) but inconsistent with Cole and Elliott (2003). This implies that regulations increase trade flow as the results of their effect on long term innovation. This is probably because these policy indices capture long-term effects of environmental regulations.

Concerning importer regulation, the coefficients in the specifications using energy intensity are statistically significant with positive sign but those using abatement cost are insignificant. In the specifications using policy indices, the coefficients are not significant in many cases, though they are significant with the positive sign in some cases. From these results, we could conclude that stricter regulations, especially regulations applied to air pollution and energy saving, in the importing country increase trade flow, since the production in importing country is decreased and demand for products of exporting country is increased, although this is weak evidence.

4.2 Difference among stringency indices

As is shown in the above, the effects of exporter stringency of environmental regulations differ among the indices. While energy intensity and abatement cost has a negative effect on the trade flow, policy indices have a positive effect. These differences are likely to result from difference in the aspects which each regulation variable captures. Thus, inclusion of multiple regulation variables in the model could contribute to obtaining more appropriate policy implications from the analysis.

We could distinguish differences among policy variables by their nature. Energy intensity is likely to capture stringency of the some specific policy that encourages energy saving that contributes to some air pollution reduction, while abatement cost is likely to capture stringency of environmental policy that covers wider range of environmental issues than energy intensity and is applied mainly to manufacturing industries. The correlation between abatement costs and energy intensity

[12] Although we also apply fixed effects estimation (the importing or exporting country effects), we find the results are almost the same as specification (a), (b), and (c).

in our sample is –0.3728, which suggests energy intensity is different type of policy variable from abatement cost. On the other hand, policy indices are likely to capture much wider range of environmental issues including regulation in the agricultural sector as well as long term effect including information on environmental legislation, the degree of citizen's environmental awareness, etc. Therefore, the effect of one policy variable is likely to capture different effect from that of the other variables. Thus, in order to capture various aspects of regulations and to identify the effect of difference in the aspects, it is important to use those variables in the model simultaneously rather than to use the single one.

In this subsection, we use multiple policy variables which are expected to capture the different aspects in policy as expressed in equation (2) and (3). It should be noted that we do not use all the regulation variables in a model simultaneously, since we lose many samples for estimation, if we use them. Thus, we first estimate equation (2) and then estimate equation (3).

First, in equation (2), we use energy intensity and abatement cost as policy variables to examine the effect of difference in two policy. Table 5[13] shows the estimation results of following model:

$$\begin{aligned} \ln Exp_{ij} = & \alpha + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln \left(K/L\right)_i + \beta_4 \ln GDPPC_j \\ & + \beta_5 \ln Dist_{ij} + \beta_6 Boarder_{ij} + \beta_7 Landlocked_{ij} + \beta_8 \ln Ene_i + \beta_9 \ln Ene_j \quad (2) \\ & + \beta_{10} \ln Abate_i + \beta_{11} \ln Abate_j + \beta_{12} RTA_{ij} + \varepsilon_{ij}, \end{aligned}$$

where *Ene* denotes energy intensity and *Abate* denotes abatement cost. The coefficient estimates for the other variables are almost the same as Table 3 and 4.[14] Table 5 suggests that exporter's abatement cost is negative and significant and the energy intensity variables are not significant. These results suggest that the regulation applied to air pollution and/or energy saving do not affect trade flow, while the regulations applied to the other types of pollution do.

(Insert Table 5)

[13] We show only the coefficient estimates for energy intensity and abatement cost because of space limitation.
[14] All of the results are available upon request from the authors.

Second, in equation (3), we use abatement cost and policy indices as policy variables. We omit energy intensity in this equation, since it is not significant in equation (2). Table 6[15] shows the estimation results of following model:

$$\begin{aligned} \ln Exp_{ij} &= \alpha + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln\left(K/L\right)_i + \beta_4 \ln GDPPC_j \\ &+ \beta_5 \ln Dist_{ij} + \beta_6 Boarder_{ij} + \beta_7 Landlocked_{ij} + \beta_8 \ln Survey_i + \beta_9 \ln Survey_j \quad (3) \\ &+ \beta_{10} \ln Abate_i + \beta_{11} \ln Abate_j + \beta_{12} RTA_{ij} + \varepsilon_{ij}, \end{aligned}$$

where *Survey* denotes WEFSTR for 2000, WEFGOV for 2001, and WEFGOV for 2003.

The coefficients of exporter's abatement cost are significant with negative sign in many cases but those of importer's one are not significant. These results are the same as the results of equation (2). These results suggest that the exporter's regulation is likely to decrease the trade flow.

On the other hand, the coefficients of exporter's survey index in most models are significant with the positive sign but those of importer's one are not significant. These results indicate that exporter's stricter regulation is likely to improve international competitiveness, while importer's regulation is not likely to affect international competitiveness of the exporter. As is discussed earlier, survey index is expected to capture the long term policy effect, while the abatement cost is expected to capture the short term policy effect.

Finely, the coefficient estimates for the other variables are not reported, since they are almost the same as Table 5.

5 Conclusions

Over time, economists have improved our understanding of the relationship between trade and environment (see Managi et al. (2009) for review). Whether there is a positive or negative relationship between environmental regulations and trade flows is crucial in determining policy recommendations for environmental preservation and international competitiveness.

Previous studies use either energy intensity, abatement cost, or survey data for regulations as a proxy for environmental policy stringency and they obtain different results. The reasons to obtain different findings are likely to be due to estimation

[15] We show only the coefficient estimates for policy indices and abatement cost because of space limitation.

method and difference in the aspects which each regulation variables capture.

In our study, we address these factors to improve the estimation method and to reconsider the effect of regulation using multiple regulation variables simultaneously.

From our analysis, we conclude that if we take into consideration not only the environmental legislation stringency but also other qualitative factors that are listed as the policy indices, in the long run, the stringency could have beneficial effects on trade flows and international competitiveness, while it could reduce trade flow and international competitiveness in the short run.

References

Anderson, J. S. 1979. A theoretical foundation for the gravity equation. American Economic Review 69 (1), 106–115.

Babool, A. and Reed, M. 2010. The impact of environmental policy on international competitiveness in manufacturing. Applied Economics (forthcoming)

Bacchetta, P., and Wincoop, E. V. 2000. Does exchange rate stability increase trade welfare? American Economic Review 90 (5), 1093–1109.

Barro, R. J. 1999. Determinants of democracy. Journal of Political Economy 107 (6), 158–183.

Baum, C. F., Schaffer, M. E., and Stillman, S. 2003. Instrumental variables and GMM: estimation and testing. Stata Journal 3, 1–31.

Bergstrand, J. H. 1985. The gravity equation in international trade: some microeconomic foundations and empirical evidence. Review of Economics and Statistics 67 (3), 474–481.

Bound, J., Jaeger, D. A., and Baker, R. 1995. Problems with instrumental variables estimation when the correlation between the instruments and the endogeneous explanatory variable is weak. Journal of the American Statistical Association 90, 443–450.

Breusch, T., Qian, H., Schmidt, P., and Wyhowski, D. 1999. Redundancy of moment conditions. Journal of Econometrics 91 (1), 89–111.

Burfisher, M. E., Robinson, Sh., and Thierfelder, K. 2001. The Impact of NAFTA on the United States. Journal of Economic Perspectives 15, 125–44.

Byrne, J. P., Darby, J., and MacDonald, R. 2008. US Trade and Exchange Rate Volatility: A Real Sectoral Bilateral Analysis. Journal of Macroeconomics 30, 238–259.

Chowdhury, H.R. 1993. Does Exchange Rate Volatility Depress Trade Flows? Evidence From Error-Correction Models. The Review of Economics and Statistics 75(4), 700–708.

Cole, M. A. and Elliott, R. J. R. 2003. Do Environmental Regulations Influence Trade Patterns? Testing Old and New Trade Theories. The World Economy, 26 (8), 1163–86.

Costantini, V., Crespi, F. 2008. Environmental Regulation and the Export Dynamics of Energy Technologies. Ecological Economics 66 (2–3), 447–460

Copeland, B.R., Taylor, M.S., 2003. Trade and the Environment:Theory and Evidence. Princeton University Press, U.S.A.

Dasgupta, S., A. Mody, S. Roy and D. Wheeler. 2001. Environmental Regulation and Development: A Cross Country Empirical Analysis. Oxford Development Studies 29 (2), 173–187.

Ederington, J. and J. Minier. 2003. Is Environmental Policy a Secondary Trade Barrier? An Empirical Analysis, Canadian Journal of Economics 36 (1), 137–154.

Eliste, P. and Fredriksson, P. G. 2001. Does Trade Liberalisation Cause a Race to the Bottom in Environmental Policies? A Spatial Econometric Analysis, in Anselin, L. and Florax, R. (eds.), New Advances in Spatial Econometrics

Frankel, J., Stein, E., and Shang-jin, W. 1995. Trading Blocs and the Americas: The Natural, the Unnatural, and the Supper-Natural. Journal of Development Economics 47 (1), 61–95.

Gould, D. M. 1998. Has NAFTA Changed North American Trade? Federal Reserve Bank of Dallas Economic Review, First Quarter, 12–23.

Harris, M. N., Konya, L., Matyas, L., 2002. Modeling the impact of environmental regulations on bilateral trade flows: OECD, 1990-1996. World Economics 25 (3), 387–405.

Hahn, J., and Hausman, J. 2002. Notes on bias in estimators for simultaneous equation models. Economics Letters 75 (2), 237–41.

International Monetary Fund. International Financial Statistics. Various Issues. Washington, D.C: IMF.

Jenkins, R. 1998. Environmental regulation and international competitiveness: a review of literature and some European evidence, Discussion Paper Series, United Nations University.

Jug, J., and Mirza, D. 2005. Environmental regulations in gravity equations: evidence from Europe. World Economics 28 (11), 1591–1615.

Kleibergen, F., and Paap, R. 2006. Generalized reduced rank tests using the singular value decomposition. Journal of Econometrics 127 (1), 97–126.

Krueger, A. O. 1999. Are Preferential Trading Agreements Trade-Liberalizing or Protectionists. Journal of Economic Perspectives 139 (4), 105–24.

Levinson, A. M. and Taylor, M. S. 2008. Unmasking the Pollution Haven Effect. International Economic Review 49 (1), 223–254.

Macguire, M. 1982. Regulation, Factor Rewards, and International Trade. Journal of Public Ecnomics, 17, 335-354.

Managi., S., Hibki, A. and T. Tsurumi. 2009. Does Trade Openness Improve Environmental Quality? Journal of Environmental Economics and Management 58 (3): 346–363.

Markusen, J. R. 1986. Explaining the Volume of Trade: An Eclectic Approach. American Economic Review 76, 1002–1011.

Nitsch, V. 2000. National Borders and International Trade: Evidence from the European Union. Canadian Journal of Economics 33 (4), 1091–1105.

Pethig, R. 1976. Pollution, Welfare, and Environmental Policy in the Theory of Comparative advantage. Journal of Environmental Economics and Management 2, 160-169.

Rose, A. K. 2005. Does the WTO Make Trade More Stable? Open Economic Review 16, 7–22.

Silva, J. M. C. S. and Tenreyro, S. 2006. The Log of Gravity. The Review of Economics and Statistics 88 (4), 641–658.

Soloaga, I., and Winters, A. 2001. Regionalism in the Nineties: What Effect on Trade? North American Journal of Economics and Finance 12 (1), 1–29.

Staiger, D., and Stock, J. H. 1997. Instrumental variables regression with weak instruments. Econometrica 65 (3), 557–86.

Stock, J. H., Wright, J. H., and Yogo, M. 2002. A Survey of Weak Instruments and

Weak Identification in Generalized Method of Moments. Journal of Business & Economic Statistics 20 (4), 518–29.

Stock, J. H., and Yogo, M. 2005. Testing for Weak Instruments in Linear IV Regression. In Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg, ed. D.W. Andrews and J. H. Stock, 80–108. Cambridge University Press.

UNCED 1990. Draft Format for National Reports. United Nations Conference on Environment and Development, Geneva.

van Beers, C., van den Bergh, J. C. J. M., 1997. An Empirical Multi-Country Analysis of the Impact of Environmental Regulations on Foreign Trade Flows. Kyklos 50, 29–46.

Wall, H. J. 2002. Has Japan Been Left Out in the Cold by Regional Integration? Federal Reserve Bank of St. Louis Review 84, 25–36.

Walter, I. and Ugelow, J. 1979. Environmentally Induced Industrial Relocation to Developing Countries. In: Rubin, S. J. and Graham, T. R. (eds.), Environment and Trade, Allanheld, Osmum, and Publishers.

World Bank. World Development Indicators. Various Issues. Washington, DC: World Bank.

World Economic Forum, 2000. The Global Competitiveness Report 2000. New York, Oxford university press.

World Economic Forum, 2002a. The Global Competitiveness Report 2001-2002. New York, Oxford university press.

World Economic Forum, 2002b. Environmental Performance Measurement: The Global Report 2001-2002. In: Esty, D. C. and Cornelius, P. K. (eds.), New York, Oxford university press.

World Economic Forum, 2004. The Global Competitiveness Report 2003-2004. In: Sala-i-Martin, X. (eds.), New York, Oxford university press.

Xinpeng, Xu., 2000. International Trade and Environment Regulation: Time Series Evidence and Cross Section Test. Environmental and Resource Economics 17 (3), 233–257.

Table 1. Previous studies

	Authors	**Stringency variable**	**Data**	**Method**	**Instruments**	**Sector**	**Result (+: positive effect on international competitiveness, -: negative effect on international competitiveness)**
Heckscher-Ohlin-Vanek (HOV) model	Tobey (1990)	1976 UNCTAD survey	23 countries, 1976	OLS	No	Five dirty sector	[Exporter's stringency] Insignificant (except for chemicals (+))
	Cole and Elliott (2003)	1992 UNCED survey and the index based on energy intensity	60 countries, 1995	2SLS	Yes	Four dirty sector	[Exporter's stringency] Insignificant
	Babool and Reed (2009)	CIESIN for 2002 and 2005	10 OECD countries, 1987-2003	Fixed effect	No	13 sector	[Exporter's stringency] Significant for most industries (+ or –) The effects depend on industries.
Gravity model	van Beers and van den Bergh (1997)	Their original index and the index based mainly on energy intensity	21 OECD countries, 1992	OLS	No	Aggregate, footloose, and dirty	[Exporter's stringency] Aggregate and footloose: Significant (–) Dirty: Insignificant [Importer's stringency] Significant (–)
	Xu (2000)	1992 UNCED survey	20 countries, 1992	OLS	No	Aggregate, environmentally sensitive goods (ESGs), and non-resource-based ESGs	[Exporter's stringency] Significant (+) [Importer's stringency] Insignificant
	Harris et al. (2002)	Index based on energy intensity	24 OECD countries, 1990-1996	Fixed effect	No	Aggregate, footloose, and dirty	[Exporter's stringency] Fixed effect: Insignificant [Importer's stringency] Insignificant
	Jug and Mirza (2005)	Total Current Expenditure (CURE)	Exporter: 19 EU countries Importer: 12 EU countries, 1996-1999	OLS, Fixed effect, and GMM with IV	Yes	9 sector	[Relative stringency] Significant (–)
	Costantini and Crespi (2008)	Total Current Expenditure (CURE)	20 OECD countries, 1996-2005	OLS, Fixed effect, FEGLS estimator, and IV estimator	Yes	Energy technology	[Exporter's relative stringency] (+)

Table 2. Details of WEF for 2000, WEFGOV for 2001, and WEFGOV for2003

Index	The definition of the index (source: ESI)
WEFSTR for 2000	Average of responses to the following survey questions: “Air pollution regulations are among the world’s most stringent”; “Water pollution regulations are among the world’s most stringent”; “Environmental regulations are enforced consistently and fairly”; and “Environmental regulations are typically enacted ahead of most other countries.”
WEFGOV for 2001	This represents the principal component of responses to several World Economic Forum survey questions touching on aspects of environmental governance: air pollution regulations, chemical waste regulations, clarity and stability of regulations, flexibility of regulations, environmental regulatory innovation, leadership in environmental policy, stringency of environmental regulations, consistency of regulation enforcement, environmental regulatory stringency, toxic waste disposal regulations, and water pollution regulations.
WEFGOV for 2003	This represents principal components of survey questions addressing several aspects of environmental governance: air pollution regulations, chemical waste regulations, clarity and stability of regulations, flexibility of regulations, environmental regulatory innovation, leadership in environmental policy, consistency of regulation enforcement, environmental regulatory stringency, toxic waste disposal regulations, and water pollution regulations.

Table 3. Gravity model estimation using energy intensity, abatement cost, and policy indices of Dasgupta et al. (2001) and Eliste and Fredriksson (2002)

Stringency data	*Energy intensity*			*Abatement costs*			*Dasgupta et al. (2001) Reference year=1992*			*Eliste and Fredriksson (2002) Reference year=1992*		
Specification	*(a)*	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*	*(j)*	*(k)*	*(l)*
year used for stringency	current-year	one-year-lagged	two-year-lagged	current-year	one-year-lagged	two-year-lagged	1992	1992	1992	1992	1992	1992
Sample period (Except for stringency)	1990–2003	1991–2003	1992–2003	1996–2003	1997–2003	1998–2003	1992	1993	1994	1992	1993	1994
ln GDP_i	0.981***	0.971***	0.974***	0.934***	0.900***	0.910***	1.036***	1.021***	0.961***	0.990***	1.010***	0.992***
	(0.010)	(0.009)	(0.009)	(0.045)	(0.054)	(0.062)	(0.073)	(0.069)	(0.068)	(0.023)	(0.023)	(0.024)
ln GDP_j	0.871***	0.853***	0.842***	0.915***	0.899***	0.828***	0.705***	0.745***	0.789***	0.804***	0.856***	0.823***
	(0.008)	(0.008)	(0.008)	(0.036)	(0.043)	(0.049)	(0.053)	(0.045)	(0.044)	(0.019)	(0.020)	(0.020)
ln Capital labor ratio$_i$	0.818***	0.808***	0.825***	1.083***	1.097***	0.944***	0.769***	0.689***	0.702***	0.495***	0.419***	0.382***
	(0.021)	(0.020)	(0.020)	(0.075)	(0.096)	(0.105)	(0.114)	(0.105)	(0.102)	(0.056)	(0.054)	(0.054)
ln GDP per capita$_j$	0.504***	0.517***	0.536***	1.190***	1.117***	1.082***	0.186	0.255**	0.233**	0.260***	0.290***	0.346***
	(0.018)	(0.018)	(0.018)	(0.095)	(0.113)	(0.152)	(0.127)	(0.117)	(0.108)	(0.056)	(0.056)	(0.057)
ln Distance$_{ij}$	–1.055***	–1.050***	–1.058***	–1.342***	–1.271***	–1.264***	–1.124***	–1.075***	–1.055***	–0.990***	–1.004***	–0.993***
	(0.015)	(0.014)	(0.014)	(0.080)	(0.093)	(0.107)	(0.137)	(0.135)	(0.129)	(0.032)	(0.032)	(0.032)
Land locked dummy$_{ij}$	–0.682***	–0.629***	–0.575***	–0.653***	–0.672***	–0.602***	–0.430	–0.205	0.178	–0.219***	–0.220***	–0.183***
	(0.034)	(0.033)	(0.031)	(0.091)	(0.102)	(0.118)	(0.368)	(0.310)	(0.275)	(0.069)	(0.068)	(0.067)
Regional trade agreement	0.234***	0.224***	0.214***	0.124***	0.216**	0.312***	0.144*	0.104**	0.099*	0.264***	0.245***	0.246***
	(0.014)	(0.013)	(0.013)	(0.093)	(0.102)	(0.126)	(0.079)	(0.051)	(0.052)	(0.021)	(0.028)	(0.025)
ln Stringency$_i$	**–0.945**	**–1.680***	**–3.441*****	**–0.312*****	**–0.193*****	**–0.132*****	**0.347**	**0.635***	**0.346**	**1.054*****	**1.273*****	**1.262*****
	(1.010)	**(0.961)**	**(0.928)**	**(0.096)**	**(0.068)**	**(0.015)**	**(0.364)**	**(0.350)**	**(0.305)**	**(0.171)**	**(0.170)**	**(0.167)**
ln Stringency$_j$	**5.587*****	**5.595*****	**5.582*****	**–0.091**	**–0.088**	**–0.123**	**0.824****	**0.570**	**0.614***	**0.971*****	**0.763**	**0.734**
	(0.581)	**(0.563)**	**(0.585)**	**(0.090)**	**(0.114)**	**(0.128)**	**(0.400)**	**(0.391)**	**(0.614)**	**(0.160)**	**(0.155)**	**(0.155)**
Constant	–21.911***	–21.347***	–21.382***	–29.127***	–28.195***	–25.176***	–21.105***	–21.884***	–20.359***	–25.371***	–26.272***	–25.226***
	(0.387)	(0.370)	(0.357)	(1.881)	(2.480)	(2.648)	(3.316)	(3.208)	(3.093)	(0.928)	(0.929)	(0.954)
R^2	0.677	0.694	0.710	0.892	0.899	0.900	0.718	0.741	0.757	0.797	0.805	0.804
Number of countries	104	104	104	17	17	17	31	31	31	60	60	60
Observations	76455	72674	64348	1568	1372	1176	676	676	676	2809	2809	2809

Notes: Robust standard errors in parentheses. i and j denote exporter and importer, respectively.
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Table 4. Gravity model estimation using the policy indices of the ESI for aggregate export flows

Stringency data	*WEFSTR Reference year=2000*			*WEFGOV Reference year=2001*			*WEFGOV Reference year=2003*
Specification	*(m)*	*(n)*	*(o)*	*(p)*	*(q)*	*(r)*	*(s)*
year used for stringency	*2000*	*2000*	*2000*	*2001*	*2001*	*2001*	*2003*
Sample period (Except for stringency)	2000	2001	2002	2001	2002	2003	2003
ln GDP_i	1.054***	1.059***	1.07***	1.194***	1.181***	1.181***	1.101***
	(0.035)	(0.036)	(0.035)	(0.054)	(0.051)	(0.050)	(0.036)
ln GDP_j	0.818***	0.816***	0.84***	0.916***	0.924***	0.903***	0.855***
	(0.039)	(0.039)	(0.038)	(0.051)	(0.050)	(0.048)	(0.038)
ln Capital labor ratio $_i$	–0.178	–0.234*	–0.261**	–0.324	–0.363	–0.370	–0.385***
	(0.127)	(0.129)	(0.128)	(0.244)	(0.237)	(0.232)	(0.105)
ln GDP per capita $_j$	–0.073	–0.095	–0.221**	–0.321	–0.335*	–0.371*	–0.141*
	(0.101)	(0.104)	(0.108)	(0.201)	(0.192)	(0.192)	(0.079)
ln Distance $_{ij}$	–0.832***	–0.852***	–0.903***	–0.836***	–0.854***	–0.859***	–0.975***
	(0.052)	(0.053)	(0.053)	(0.064)	(0.063)	(0.061)	(0.054)
Land locked dummy $_{ij}$	–0.104	–0.048	–0.002	0.213	0.243	0.256	–0.056
	(0.150)	(0.152)	(0.150)	(0.173)	(0.169)	(0.166)	(0.147)
Regional trade agreement	0.259***	0.245***	0.233***	0.436***	0.442***	0.444***	0.168***
	(0.042)	(0.044)	(0.044)	(0.097)	(0.096)	(0.094)	(0.052)
ln Stringency $_i$	**1.211*****	**1.346*****	**1.355*****	**0.194*****	**0.192*****	**0.185*****	**2.182*****
	(0.409)	**(0.418)**	**(0.417)**	**(0.056)**	**(0.055)**	**(0.054)**	**(0.450)**
ln Stringency $_j$	**0.660**	**0.599**	**1.175****	**0.029**	**0.027**	**0.055**	**0.859****
	(0.420)	**(0.432)**	**(0.453)**	**(0.092)**	**(0.089)**	**(0.087)**	**(0.406)**
Constant	–22.064***	–21.307***	–20.926***	–21.433***	–20.537***	–19.391***	–29.057***
	(1.673)	(1.722)	(1.714)	(3.420)	(3.276)	(3.265)	(1.958)
R^2	0.561	0.550	0.561	0.659	0.666	0.671	0.576
Number of countries	Exporter: 42	Exporter: 42	Exporter: 42	Exporter: 40	Exporter: 40	Exporter: 40	Exporter: 40
	Importer: 43	Importer: 43	Importer: 43	Importer: 41	Importer: 41	Importer: 41	Importer: 41
Observations	1806	1806	1806	1640	1640	1640	1640

Notes: Robust standard errors in parentheses. i and j denote exporter and importer, respectively.
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Table 5. Gravity model estimation using stringency indices

Stringency data	*Energy intensity and Abatement cost Reference year=2000*			*Energy intensity and Abatement cost Reference year=2001*			*Energy intensity and Abatement cost Reference year=2003*
Specification	*(m)*	*(n)*	*(o)*	*(p)*	*(q)*	*(r)*	*(s)*
Sample period (Except for stringency)	2000	2001	2002	2001	2002	2003	2003
ln Energy intensity$_i$	**0.413**	**0.391**	**0.394**	**0.391**	**0.394**	**0.384**	**0.188**
	(0.437)	**(0.443)**	**(0.411)**	**(0.443)**	**(0.411)**	**(0.402)**	**(0.409)**
ln Energy intensity$_j$	**0.525**	**0.688**	**0.592**	**0.688**	**0.593**	**0.568**	**0.589**
	(0.456)	**(0.465)**	**(0.455)**	**(0.465)**	**(0.455)**	**(0.464)**	**(0.450)**
ln Abatement cost$_i$	**–0.436*** **	**–0.464*** **	**–0.470*** **	**–0.464*** **	**–0.470*** **	**–0.498*** **	**–0.482*** **
	(0.157)	**(0.163)**	**(0.155)**	**(0.163)**	**(0.155)**	**(0.164)**	**(0.153)**
ln Abatement cost$_j$	**–0.141**	**–0.091**	**–0.132**	**0.090**	**–0.132**	**–0.146**	**–0.151**
	(0.136)	**(0.137)**	**(0.133)**	**(0.137)**	**(0.133)**	**(0.124)**	**(0.130)**
Number of countries	17	17	17	17	17	17	17
Observations	272	272	272	272	272	272	272

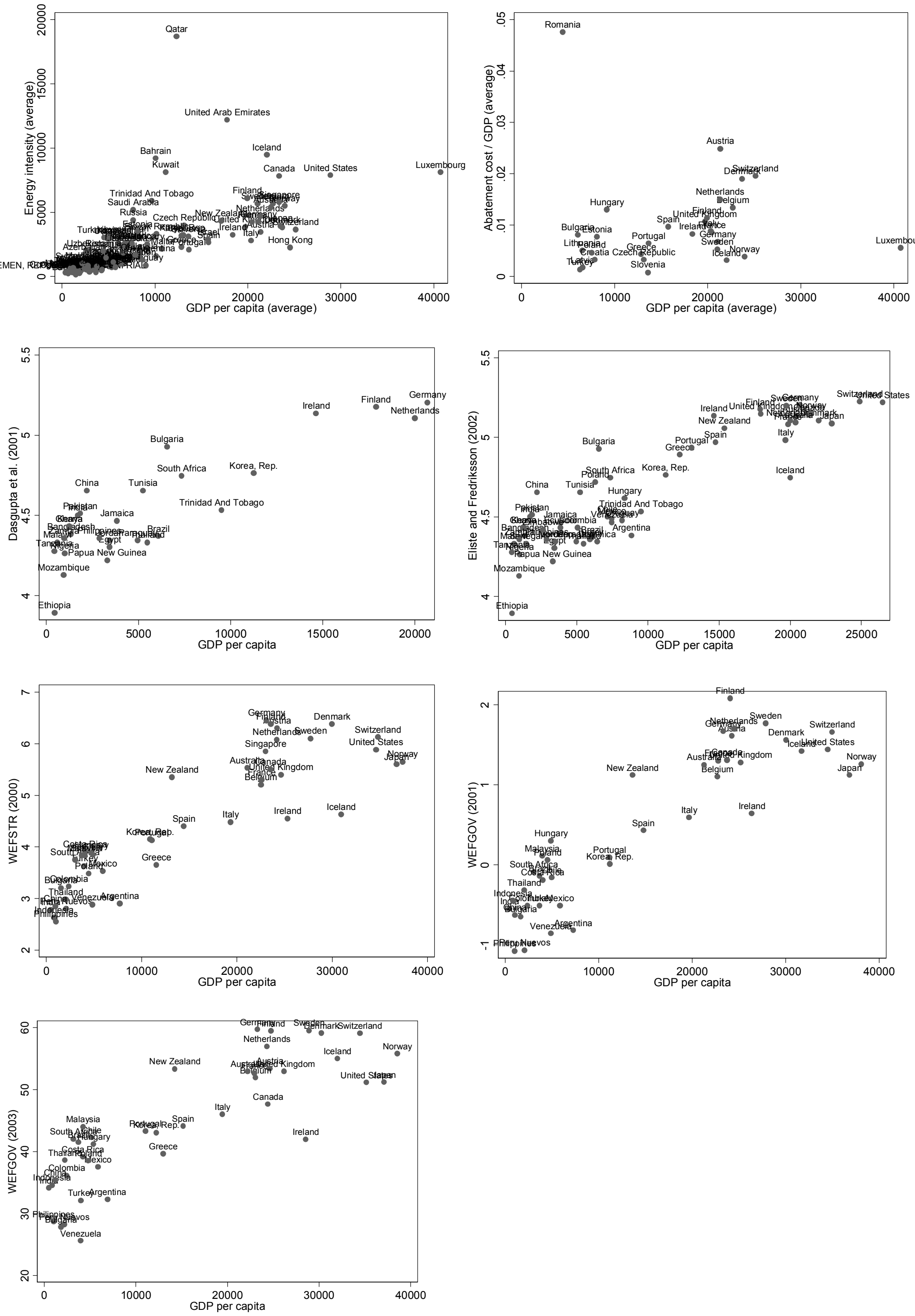
Notes: Robust standard errors in parentheses. i and j denote exporter and importer, respectively.
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Table 6. Gravity model estimation using stringency indices

Stringency data	*WEFSTR and Abatement cost Reference year=2000*			*WEFGOV and Abatement cost Reference year=2001*			*WEFGOV and Abatement cost Reference year=2003*
Specification	*(m)*	*(n)*	*(o)*	*(p)*	*(q)*	*(r)*	*(s)*
Sample period (Except for stringency)	2000	2001	2002	2001	2002	2003	2003
ln WEFSTR$_i$ or ln WEFGOV$_i$	**1.473*** (0.844)**	**1.442*** (0.844)**	**1.290 (0.807)**	**0.577*** (0.151)**	**0.560*** (0.146)**	**0.494*** (0.146)**	**–0.015 (1.213)**
ln WEFSTR$_j$ or ln WEFGOV$_j$	**0.373 (0.928)**	**0.270 (0.927)**	**0.355 (0.915)**	**0.128 (0.229)**	**0.160 (0.221)**	**0.148 (0.225)**	**1.186 (1.401)**
ln Abatement cost$_i$	**–0.390** (0.157)**	**–0.416** (0.163)**	**–0.431*** (0.150)**	**–0.219 (0.196)**	**–0.231 (0.184)**	**–0.223 (0.183)**	**–0.488*** (0.148)**
ln Abatement cost$_j$	**–0.076 (0.134)**	**–0.027 (0.136)**	**–0.075 (0.132)**	**0.130 (0.154)**	**–0.162 (0.152)**	**–0.181 (0.149)**	**–0.132 (0.129)**
Number of countries	17	17	17	17	17	17	17
Observations	272	272	272	272	272	272	272

Notes: Robust standard errors in parentheses. i and j denote exporter and importer, respectively.
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Figure 1. Simple scatter plots between stringency indices and GDP per capita



Appendix A

Table A.1 Country list for energy intensity and abatement cost

Energy intensity 104 countries						Abatement cost 17 countries
Albania	Costa Rica	Hong Kong	Macedonia	Russia	Uruguay	Belgium
Algeria	Cote D Ivoire	Hungary	Malaysia	Senegal	Venezuela	Denmark
Argentina	Croatia	Iceland	Mexico	Slovak Republic	Zambia	Finland
Armenia	Czech Republic	India	Moldova	Slovenia	Zimbabwe	France
Australia	Denmark	Indonesia	Morocco	South Africa		Germany
Austria	Dominican Republic	Iran	Mozambique	Spain		Hungary
Azerbaijan	Ecuador	Ireland	Nepal	Sri Lanka		Iceland
Bangladesh	Egypt	Israel	Netherlands	Sweden		Italy
Belarus	El Salvador	Italy	New Zealand	Switzerland		Netherlands
Belgium	Estonia	Jamaica	Nicaragua	Syrian Arab Republic		Norway
Benin	Ethiopia	Japan	Nigeria	Tajikistan		Poland
Bolivia	Finland	Jordan	Norway	Tanzania		Portugal
Brazil	France	Kazakhstan	Pakistan	Thailand		Spain
Bulgaria	Gabon	Kenya	Panama	Togo		Sweden
Cameroon	Georgia	Korea, Rep.	Paraguay	Trinidad And Tobago		Turkey
Canada	Germany	Kyrgyz	Peru Nuevos	Tunisia		United Kingdom
Chile	Ghana	Republic	Philippines	Turkey		United States
China	Greece	Latvia	Poland	Ukraine		
Colombia	Guatemala	Lebanon	Portugal	United Kingdom		
Congo,	Honduras	Lithuania	Romania	United States		
Republic Of		Luxembourg				

Table A.2 Country list for policy indices

Dasgupta et al. (2001) 31 countries		Eliste and Fredriksson (2002) 62countries				WEFSTR for 2000, WEFGOV for 2001, and WEFGOV for 2003 43countries		
Bangladesh	Malawi	Argentina	Ethiopia	Malawi	Sweden	Argentina	Hungary	Portugal
Bhutan	Mozambique	Australia	Finland	Mexico	Switzerland	Australia	Iceland	Singapore**
Brazil	Netherlands	Austria	France	Morocco	Tanzania	Austria	India	South Africa
Bulgaria	Nigeria	Bangladesh	Germany	Mozambique	Thailand	Belgium	Indonesia	Spain
China	Pakistan	Belgium*	Ghana	Netherlands	Trinidad	Brazil	Ireland	Sweden
Egypt	Papua New	Brazil	Greece	New	and Tobago	Bulgaria	Italy	Switzerland
Ethiopia	Guinea	Bulgaria	Hungary	Zealand	Tunisia	Canada	Japan	Thailand
Finland	Paraguay	Canada	Iceland	Nigeria	Turkey	Chile	Korea, Rep.	Turkey
Germany	Philippines	Chile	India	Norway	United	China	Malaysia	United
Ghana	South Africa	China	Ireland	Pakistan	Kingdom	Colombia	Mexico	Kingdom
India	Switzerland	Colombia	Italy	Papua New	United	Costa Rica	Netherlands	United States
Ireland	Tanzania	Czechoslovakia	Jamaica	Guinea	States	Denmark	New Zealand	Venezuela
Jamaica	Thailand	Denmark	Japan	Paraguay	Uruguay	Finland	Norway	
Jordan	Trinidad and	Dominican	Jordan	Philippines	Venezuela	France	Peru Nuevos	
Kenya	Tobago	Republic*	Kenya	Poland	Zambia	Germany	Philippines	
Korea,	Tunisia	Ecuador	Korea,	Portugal	Zimbabwe	Greece**	Poland	
Rep.	Zambia	Egypt	Rep.	Senegal				
				South Africa				
				Spain				

Note: * not included in the estimation due to data limitation. ** not included in our gravity-model using WEFGOVE for 2001 and 2003 due to data limitation.

Appendix B: (*Unsuccessful*) Search of Instrumental Variables

Higher levels of net imports may result in the relaxation of environmental regulations, while relaxed environmental regulations may affects trade flows (Trefler, 1993). This is because we need to consider simultaneous problem of these two variables.

We consider two factors that influence the stringency. These are environmental quality as a normal good and the cost of compliance. A country that strengthens its environmental regulations can be seen as a member of a group of nations that is voluntarily providing a public good. This is because additional demand for environmental quality comes with higher level of wealth. We follow Cole and Elliott (2003) suggesting that the key determinant of stringency is per capita income, and considering a country's average GNP per capita and the lagged five years as an instrumental variable. We use a country's average GNP per capita, and lagged five years as IVs. Following Ederington and Minier (2003)[16], we also consider political-economy variable as IV.[17] Furthermore, we also consider IV proposed by Rose and Spiegel (2009). They use the Environmental Sustainability Index (ESI) developed by the Yale Center for Environmental Law and Policy (YCELP) and the Center for International Earth Science Information Network (CIESIN) at Columbia University as an instrumental variable. They apply the ESI and its underlying components[18] as measures of actual and potential environmental damage. We assume that these are strongly correlated with the stringency variables, while these do not seem to directly affect trade flows, and thus be weakly correlated with the environmental regulations. Rose and Spiegel (2009) also incorporate adjusted savings from CO_2 damage and adjusted savings from particulate emission damage as IV. These are also considered as measures of actual and potential environmental damage. To include these IV in the model, we use two-stage least squares (2SLS) with robust standard errors.

[16] Ederington and Minier (2003) obtain significant results using United States (US) state level abatement costs. They use ratio of pollution abatement costs and expenditure (PACE) to total costs of materials for 1978–1992 as stringency. They find a positive effect of US abatement costs on US net imports. They consider simultaneous problem of environmental regulations because "both the political economy and trade theories suggest that higher levels of net imports may result in the relaxation of environmental regulations". As a result, they find that its estimated effect on trade flows is significantly higher than previously reported when stringency is modeled as an endogenous variable.

[17] Jug and Mirza (2005) also consider the endogeneity of environmental regulations. Because of data limitation, we are not able to incorporate their instrumental variables in this paper. Those data are available only for EU countries.

[18] These are environmental systems, environmental stress, and human vulnerability.

GNP per capita is from World Development Indicators. As political-economy variables we obtain "polity" score obtained from the Polity IV dataset.[19] The ESI and the underlying components are from YCELP and SIESIN.[20] Because we are able to obtain them only for 2000 and 2001, we use the averaged values of these years as IV for all estimations. Adjusted savings from CO_2 damage and adjusted savings from particulate emission damage are from World Development indicators.[21] Following Rose and Spiegel (2009), we use values that are averaged over the past five years as IV.

We apply 2SLS using equation (1). To verify the appropriateness of IV, we apply three tests: the underidentification test, the weak identification test, and overidentification test.

The rank condition must be satisfied to estimate equation (1), that is, excluded instruments must be correlated with the endogenous regressors. The consequence of utilizing excluded instruments that are uncorrelated with the endogenous regressios is increased bias in the estimated IV coefficients (Hahn and Hausman, 2002). Recently, several robust statistics for testing the rank of a matrix have been proposed. Among them, we adopt the rk statistic proposed by Kleibergen and Paap (2006) because this test is robust to heteroskedasticity. We apply the Kleibergan-Paap rk LM statistics for underidentification test and as a result, pass this test.[22]

On the other hand, Bound et al. (1995) and Staiger and Stock (1997) have shown that the weak instrumental problem can arise even if the underidentification test is passed and large sample is used (see Staiger and Stock, 1997; Stock et al., 2002). For weak identification test, we adopt the Kleibergen-Paap rk Wald F statistics since this test is also robust to heterogeneity and, as a consequence, passed this test.[23]

For overidentification test, we examine Hansen J statistics. The null hypothesis is the

---

[19] See http://www.cidcm.umd.edu/inscr/polity/. This index ranges from -10 (a high autocracy) to 10 (a high democracy).

[20] The ESI was constructed by aggregation of five components. These are the state of the environmental system, the stresses on those systems, the human vulnerability to environmental change, the social and institutional capacity to cope with environmental challenges, and the ability to respond to the demands of global stewardship (see Rose and Spiegel, 2009 for more information).

[21] Carbon dioxide damage is estimated to be $20 per ton of carbon (the unit damage in 1995 U.S. dollars) times the number of tons of carbon emitted. Particulate emissions damage is calculated as the willingness to pay to avoid mortality attributable to particulate emissions.

[22] We also use an IV redundancy test shown by Breusch et al. (1999) to drop redundant instruments since using a large number of instruments can cause the estimator to have poor finite sample performance. The results of this test were almost the same as the underidentificaton test.

[23] We refer to "rule of thumb" of Staiger and Stock (1997), which says that the F-test should be greater than 10. We also checked the test of Stock and Yogo (2005) version of the Cragg-Donald statistic and passed.

instruments are valid instruments, i.e., uncorrelated with the error term. Our p-values of this test are higher than 0.10 for all cases and therefore passed this test. This implies that excluded instruments are correctly excluded from the estimated equation.

Table B shows the results of above tests for specification (a) to (s) in equation (1). (A), (B), (C), and (D) are estimated separately using 2SLS. As we see in Table B.1 and B.2, we are not able to find an appropriate instrumental variable.

Table B.1 Two-stage least squares

Stringency data		*Energy intensity*			*Abatement costs*			*Dasgupta et al. (2001) Reference year=1992*			*Eliste and Fredriksson (2002) Reference year=1992*		
Specification		*(a)*	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*	*(j)*	*(k)*	*(l)*
(A)GNP per capita & polity	Under-identification	198.817***	195.647***	179.377***	7.739**	7.546**	7.879**	27.144***	20.580***	20.937***	164.705***	174.187***	174.448***
	Weak-identification	107.912	103.768	111.414	3.179	2.843	3.011	24.952	21.896	23.502	141.031	137.405	120.404
	Over-identification	25.389***	27.754***	25.355***	5.327**	4.696**	5.121**	0.063	1.140	1.154	2.999*	1.883	0.942
(B)CO_2 damage & PM damage	Under-identification	1530.366***	1424.757***	1497.159***	71.203***	64.519***	68.728***	29.246***	27.405***	28.455***	91.540***	94.797***	86.723***
	Weak-identification	365.757	347.649	352.686	31.452	26.718	27.656	8.203	7.077	7.218	22.712	23.801	21.425
	Over-identification	6.889**	7.427**	6.114**	6.488**	8.212**	7.455**	0.529	1.849	1.023	0.876	1.213	7.192**
(C)ESI & polity	Under-identification	555.895***	542.187***	545.858***	22.106***	21.954***	21.457***	22.767***	21.626***	21.344***	157.765***	174.955***	184.302***
	Weak-identification	188.455	194.336	189.474	5.453	5.144	5.241	12.785	15.205	17.377	111.539	109.427	104.612
	Over-identification	64.416***	57.347***	54.969***	8.096**	8.545**	7.347**	13.299***	8.569**	6.951**	5.944*	3.397	1.065
(D)ESI components & polity	Under-identification	618.670***	678.141***	681.487***	56.715***	56.414***	57.674***	39.046***	32.425***	32.072***	271.573***	289.792***	301.384***
	Weak-identification	77.356	74.112	76.747	11.960	10.468	11.974	60.439	66.053	61.817	139.552	135.629	53.807
	Over-identification	427.621***	465.487***	498.473***	74.943***	77.143***	67.975***	22.977***	21.525***	17.519***	51.455***	69.667***	53.807***

Notes: Robust standard errors in parentheses. (A), (B),(C), and (D) are estimated separately using equation (1).
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Table B.2 Two-stage least squares

Stringency data	*test*	*WEFSTR Reference year=2000*			*WEFGOV Reference year=2001*			*WEFGOV Reference year=2003*
Specification		*(m)*	*(n)*	*(o)*	*(p)*	*(q)*	*(r)*	*(s)*
(A)GNP per capita & polity	Under-identification	27.957***	27.448***	23.548***	1.777	2.361	2.233	10.401
	Weak-identification	17.709	15.540	11.743	0.497	0.633	0.597	4.912
	Over-identification	0.212	0.225	0.058	24.459***	26.980***	21.730***	0.901
(B)CO_2 damage & PM damage	Under-identification	37.896***	32.569***	28.326***	24.497***	25.399***	26.649***	35.743***
	Weak-identification	11.008	9.267	7.960	6.170	6.427	6.800	9.313
	Over-identification	31.745***	30.311***	26.769***	33.300***	33.214***	35.488***	59.478***
(C)ESI & polity	Under-identification	118.228***	121.946***	123.208***	51.163***	50.097***	52.222***	65.915***
	Weak-identification	42.115	40.316	39.213	16.663	16.649	17.618	18.112
	Over-identification	13.219***	15.481***	18.191***	21.844***	19.255***	16.686***	7.901**
(D)ESI components & polity	Under-identification	151.218***	139.793***	112.905***	169.532***	171.227***	172.418***	62.762***
	Weak-identification	28.776	27.570	21.557	32.746	31.864	32.323	8.411
	Over-identification	73.884***	73.512***	71.144***	40.193***	34.622***	29.646***	20.909***

Notes: Robust standard errors in parentheses. (A), (B), (C), and (D) are estimated separately using equation (1).
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Appendix C: Decomposed Indices

The decomposed indices are available for WEFSTR for 2000, WEFGOV for 2001, and WEFGOV for 2003, which we obtain these decomposed indices from World Economic Forum (2000), World Economic Forum (2002a), and World Economic Forum (2004). These indices' summary statistics and the survey questions are shown in Table C.1 and Table C.2, respectively.

(Insert Table C.1 and C.2)

We apply gravity model of equation (1) using these decomposed indices. Table C.3 presents the estimation results.

(Insert Table C.3)

We show only the coefficient estimates for exporter and importer policy indices for the same reason as Table 4. The result suggests that all the components for export countries have positive effects on its export flows.

Correlation among these indices is shown in Table C.4, implying that there are strong correlations among them.

Table C.1 Summary statistics of the ESI indices

Index	Number of countries	Mean	S. D.	Min.	Max.
WEFSTR for 2000	43	4.515402	1.240963	2.55	6.45
overall	43	4.698113	1.338276	2.5	6.6
leader	43	4.415374	1.239829	2.7	6.7
cla_sta	43	4.498952	0.801061	3.4	6.5
flex	43	4.143326	0.375913	3.5	5.1
enforce	43	4.332355	1.031684	2.6	6
WEFGOV for 2001	41	2.447317	0.945984	1.08	4.08
overall	43	4.904651	1.293197	2.5	6.7
leader	43	4.465116	1.288573	2.4	6.6
cla_sta	43	4.525581	0.889915	3	6.7
flex	43	4.095349	0.542899	3.1	5.4
enforce	43	4.490698	1.102986	2.7	6.4
WEFGOV for 2003	41	44.52381	9.94918	25.6	59.74
overall	43	4.87907	1.184736	2.7	6.7
leader	43	4.55814	1.19647	2.4	6.5
cla_sta	43	4.55814	0.837295	3.1	6.1
flex	43	4.253488	0.624633	3	5.4
enforce	43	4.490698	1.075665	2.1	6.1

Table C.2. Definition of decomposed indices

Index		Definition
overall	Stringency of environmental regulations	The stringency of overall environmental regulations in your country is: (1=lax compared with most other countries, 7=among the world's most stringent)
leader	Leadership in environmental policy	Compared with other countries, your country normally enacts environmental regulations: (1 = much later, 7 = ahead of most others)
cla_sta	Clarity and stability of regulations	Environmental regulations in your country are: (1 = confusing and frequently changing, 7 = transparent and stable)
flex	Flexibility of regulations	Environmental regulations in your country: (1 = offer no options for achieving compliance, 7 = are flexible and offer many options for achieving compliance)
enforce	Consistency of regulation enforcement	Environmental regulation in your country is: (1 = not enforced or enacted erratically, 7 = enforced consistently and fairly)

Table C.3 Estimation results of decomposed indices

Stringency data		*WEFSTR* *Reference year=2000*			*WEFGOV* *Reference year=2001*			*WEFGOV* *Reference year=2003*
Specification		*(m)*	*(n)*	*(o)*	*(p)*	*(q)*	*(r)*	*(s)*
year used for stringency		*2000*	*2001*	*2002*	*2001*	*2002*	*2003*	*2003*
(A)	*ln* $OVERALL_i$	0.769*	0.935**	0.986**	1.516***	1.592***	1.791***	1.261***
		(0.452)	(0.462)	(0.464)	(0.340)	(0.342)	(0.338)	(0.367)
	ln $OVERALL_j$	0.501	0.426	1.048**	0.289	0.831**	0.886**	0.865**
		(0.453)	(0.466)	(0.491)	(0.384)	(0.400)	(0.387)	(0.350)
(B)	*ln*$LEADER_i$	0.862***	0.939***	0.914***	1.349***	1.399***	1.526***	1.305***
		(0.328)	(0.337)	(0.337)	(0.302)	(0.305)	(0.297)	(0.321)
	ln$LEADER_j$	0.262***	0.200	0.594	0.137	0.462	0.453	0.815**
		(0.361)	(0.369)	(0.384)	(0.341)	(0.350)	(0.341)	(0.316)
(C)	*ln* CLA_STA_i	2.556***	2.668***	2.671***	2.936***	2.984***	3.141***	2.478***
		(0.442)	(0.450)	(0.447)	(0.386)	(0.387)	(0.380)	(0.411)
	ln CLA_STA_j	0.232	0.129	0.602	0.245	0.584	0.720	0.586
		(0.456)	(0.463)	(0.478)	(0.395)	(0.406)	(0.396)	(0.410)
(D)	*ln* $FLEX_i$	5.275***	5.233***	5.217***	5.735***	5.679***	5.692***	2.773***
		(0.748)	(0.761)	(0.751)	(0.459)	(0.456)	(0.447)	(0.453)
	ln $FLEX_j$	2.728***	2.606***	3.243***	0.877*	1.072**	1.173***	0.723***
		(0.791)	(0.803)	(0.810)	(0.456)	(0.457)	(0.451)	(0.488)
(E)	*ln* $ENFORCE_i$	1.211***	1.290***	1.293***	1.516***	1.531***	1.681***	1.640***
		(0.404)	(0.414)	(0.412)	(0.350)	(0.352)	(0.348)	(0.361)
	ln $ENFORCE_j$	0.790**	0.763*	1.441***	0.628*	1.132***	1.138***	0.922***
		(0.393)	(0.404)	(0.425)	(0.362)	(0.378)	(0.368)	(0.322)

Notes: Robust standard errors in parentheses. i and j denote exporter and importer, respectively. (A), (B), (C), (D), and (E) are estimated separately using equation (1).
*, **, and *** denote significance at 90, 95, and 99 per cent, respectively.

Table C.4 Correlation among the ESI indices

	WEFSTR for 2000	overal	leader	cla_sta	flex	enforce
WEFSTR for 2000	1					
overall	0.9926	1				
leader	0.9858	0.9735	1			
cla_sta	0.928	0.9134	0.9078	1		
flex	0.7659	0.7614	0.7335	0.8525	1	
enforce	0.9718	0.9608	0.9362	0.9394	0.8122	1
	WEFGOV for 2001	overal	leader	cla_sta	flex	enforce
WEFGOV for 2001	1					
overall	0.9861	1				
leader	0.9733	0.9744	1			
cla_sta	0.9357	0.8886	0.8876	1		
flex	0.7939	0.7079	0.6987	0.8318	1	
enforce	0.9869	0.9637	0.9434	0.9373	0.8083	1
	WEFGOV for 2003	overal	leader	cla_sta	flex	enforce
WEFGOV for 2003	1					
overall	0.9854	1				
leader	0.98	0.986	1			
cla_sta	0.9328	0.9101	0.9226	1		
flex	0.8588	0.8329	0.835	0.9405	1	
enforce	0.9738	0.9668	0.9602	0.9222	0.8609	1

Appendix D: Commodity level Estimations

It is somewhat unexpected that we find positive effects of environmental regulations on international competitiveness. For a robustness check, we apply commodity level analysis (2 digit HS code) using WEFSTR for 2000, WEFGOV for 2001, and WEFGOV for 2003.

The commodity level model is as follows:

$$\begin{aligned}\ln Exp_{ijk} = \alpha &+ \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln\left(K/L\right)_i + \beta_4 \ln GDPPC_j \\ &+ \beta_5 \ln Dist_{ij} + \beta_6 Boarder_{ij} + \beta_7 Landlocked_{ij} \\ &+ \beta_8 \ln Survey_i + \beta_9 \ln Survey_j \qquad (4) \\ &+ \beta_{10} \ln Survey_i \cdot \ln\left(K/L\right)_i + \beta_{11} \ln Survey_j \cdot \ln GDPPC_j \\ &+ \beta_{12} RTA_{ij} + \varepsilon_{ij},\end{aligned}$$

where Exp_{ijk} denotes export flow of commodity k. The difference from equation (1) is that this model includes cross terms. The effects of environmental regulations on commodity level trade are expected to depend on whether the exporting country is capital intensive or not and the commodity is luxury or not. To control these characteristics, we apply commodity level analysis.

Table D.1 shows the estimation results (the signs of the elasticity of WEFSTR for 2000). We also present the sign of OECD and non-OECD countries evaluated from these countries sample mean. We obtain statistically significant positive signs for most commodities. As another robustness check, Table D.1 presents the estimation result using poisson model.[24] The poisson model is as follows:

[24] Silva and Tenreyro (2006) suggests the problems with log-lairizing in gravity model. They mention that the variance of the error term may be dependent of the countries' GDPs and of the various measures of distance, and also mention that pairs of countries with zero bilateral exports have to be dropped out of the sample, as a result of the logarithmic transformation. In our estimation, the number of observation of the poisson model increase by about 30% compared with that of OLS.

$$
\begin{aligned}
Exp_{ijk} = {} & \alpha + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln\left(K/L\right)_i + \beta_4 \ln GDPPC_j \\
& + \beta_5 \ln Dist_{ij} + \beta_6 Boarder_{ij} + \beta_7 Landlocked_{ij} \\
& + \beta_8 \ln Survey_i + \beta_9 \ln Survey_j \qquad (5) \\
& + \beta_{10} \ln Survey_i \cdot \ln\left(K/L\right)_i + \beta_{11} \ln Survey_j \cdot \ln GDPPC_j \\
& + \beta_{12} RTA_{ij} + \varepsilon_{ij},
\end{aligned}
$$

The results are almost the same as that using OLS.

Next, using both equation (4) and equation (5), we show the elasticity in the case of aggregate trade flows in Table D.2. We present not only the results using WEFSTR for 2000, but also its decomposed indices. The results are also almost the same as Table 3. Due to space limitation, we do not present the results of WEFGOV for 2001 and its components and WEFGOV for 2003 and its components. The results of the elastisities of these indices have almost the same characteristics as Table D.1 and Table D.2.

Table D.1 Commodity level estimations in the case of WEFSTR for 2000 using equation (4) and (5)

	ALL												OECD												nonOECD											
Method	OLS						poisson						OLS						poisson						OLS						poisson					
Sample period (Except for stringency)	2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002	
Exporter: A Importer: B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	+		+	–	+		+		+		+		+		+	–	+		–		–		–		+		+	+	+		+		+		+	
2	+		+		+		–						+		+		+		–						+		+		+		+					
3																																				
4	+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+	
5	+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		–		–		+	+	+	+	+	+	+		+		+	
6	+		+		+	+						+	+		+		+	+						+	+		+		+	+						+
7	–		+		–		–		–		–		–		–		–		–		–		–		+		+		+		–		–		–	
8	+		+		+		–		–		–		–		–		–		–		–		–		+		+		+		+		+		+	
9	+		+	+	+	+	+		+	+	+	+	+		+	+	+	+	+		+	+	+	+	+		+	+	+	+	+		+	+	+	+
10			–		–										–		–										+		+							
11	+		+		+		–		–		–		+		+		+		–		–		–		+		+		+		+		+		+	
12	+	+	+		+		+		+		+		+	+	+		+		+		+		+		+	+	+		+		+		+		+	
13	+		+		+								+		+		+								+		+		+							
14							+		+		+								–		–		–								+		+		+	
15				+		+	–		–	–	–					+		+	–		–	–	–					+		+	–		+	+	+	
16	–		–		–								–		–		–								–		–		+							
17	+		+		+		–	–	–		–		+		+		+		–	–	–		–		+		+		+		+	–	+		+	
18				–		+	+		+	–	+					–		–	+		+	–	+					+		+	+		+	+	+	
19	+						+				+		+						+				–		+						+				+	
20	+		+		+		–		–		–		–		–		–		–		–		–		+		+		+		+		+		+	
21	+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+	
22	+		+		+	+	+		+		+	–	+		+		+	+	+		+		+	–	+		+		+	+	+		+		+	+
23							–	–		–		–							–	–		–		–							+	–		–		–
24	+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+	
25	+		+		+		+		+		+		+		+		+		–		–		–		+		+		+		+		+		+	
26	+		+		+		+		+		+		+		–		+		+		+		+		+		+		+		+		+		+	
27			+	+		+	+		+		+				+	+		+	+		+		+				+	+		+	+		+		+	

Note: We only present statistically significant signs.

Table D.1 (continued…)

	ALL												OECD												nonOECD											
Method	OLS						poisson						OLS						poisson						OLS						poisson					
Sample period (Except for stringency)	2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002	
Exporter: A Importer: B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
28			+	+	+	+	+		+		+				+	+	+	+	+		+		+				+	+	+	+	+		+		+	
29		+		+		+	+	+	+	+	+	+		–		+		+	+	–	+	+	+	+		+		+		+	+	+	+	+	+	+
30	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	–	+	–	+	–	+	+		+	+	+	+	+	+	+	+	+
31	+	+	+	–	+	+	+		+		+		+	–	+	–	+	–	+		+		+		+	+	+	–	+	+	+		+		+	
32		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+
33	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	–	+	–	+	–	+	+	+	+	+	+	+	+	+	+	+	+
34		+		+	+	+	+		+		+			+		+	+	+	+		–		–			+		+	+	+	+		+		+	
35	+		+	+	+	+	+		+				+		+	+	+	+	+		+				+		+	+	+	+	+		+			
36	+		+	+	+	+						+	+		+	+	-	+						+	+		+	+	+	+						+
37	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+
38		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+
39		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+
40		+	+	+	+	+	–		–		–			+	–	+	–	+	–		–		–			+	+	+	+	+	–		–		–	
41	+	+	+	+	+	+	+	–	+	–	+	–	+	+	+	–	+	+	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	–	+	–
42	–		–		+	+				+	–	+	–		+		+	+				–	–	–	–		–		–	+				+	+	+
43	+	+	+		+	+	–	+	–	+	–	+	+	+	–		+	+	–	–	–	–	–	–	+	+	+		+	+	+	+	+	+	+	+
44	+				+								+				+								+				+							
45	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	+	+	+	+	+	+	+	+	+
46	–		–		–			–	–		–		–		–		–			–	–		–		–		–		–			–	–		–	
47	+	–	+		+	+	+		+		+		+	+	+		+	+	+		+		+		+	–	+		+	–	+		+		+	
48		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+
49		+		+		+	+	+	+		+			+		+		+	+	+	+		+			+		+		+	+	+	+		+	
50				+		+		+		+						–		+		–		+						+		+		+		+		
51	+	+	+		+		+	–	+	–	+	–	+	+	+		+		+	–	+	–	+	–	+	+	+		+		+	–	+	–	+	–
52		+	–		–	+	+	–	+		+			+	–		–	+	–	–	+		–			+	–		+	+	+	+	+		+	
53		+		+		+	+		+		+			+		–		+	+		+		+			+		+		+	+		+		+	
54		+	–	+	+	+	+	+	+	+	+	+		–	–	+	–	+	+	–	+	–	+	+		+	–	+	+	+	+	+	+	+	+	+

Note: We only present statistically significant signs.

Table D.1 (continued…)

	ALL												OECD												nonOECD											
Method	OLS						poisson						OLS						poisson						OLS						poisson					
Sample period (Except for stringency)	2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002	
Exporter: A Importer: B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
55		+		+		+	–		–		–			+		–		+	–		–		–			+		+		+	+		+		+	
56		+	–	+	+	+	+	+	+	+	+	+		+	–	+	–	+	+	+	+	+	+	–		+	+	+	+	+	+	+	+	+	+	+
57	+		+		+		+	+	+		+		+		+		+		+	+	+		+		+		+		+		+	+	+		+	
58	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	–	+	–	+	–	+	+		+	+	+	+	+	+	+	+	+
59	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
60	–	+	+	+	–	+	+	+	+	+	+	+	–	+	–	+	–	+	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+
61	–		–		–	+	+	+	+	+	+	+	–		–		–	+	–	+	–	+	–	+	–		–		–	+	+	+	+	+	+	+
62	–		–		–		+	+	+	+	+	+	–		–		–		–	+	–	+	–	+	–		–		–		+	+	+	+	+	+
63							+	+	+	+	+	+							+	+	+	+	+	+							+	+	+	+	+	+
64						+	–		–		–							+	–		–		–							+	–		–		–	
65		+	–	+		+			–		–			+	–	+		+			–		–			+	–	+		+			–		+	
66			+				+	+	+	+	+	+			+				–	+	–	+	–	+			+				+	+	+	+	+	+
67						+												+												+						
68	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	–	+	–	–	+	+	+	+	+	+	+	+	+	+	+	+
69	–		–	+	–	+	–	+	–	+	–	+	–		–	+	–	+	–	–	–	–	–	–	–		+	+	+	+	+	+	+	+	+	+
70	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	–	+	+	+	+	+	+	+	+		+	+	+	+
71							+		+	–	+								+		+	–	+								+		+	–	+	
72	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
73	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
74	+		+		+		+		+	+	+	+	+		+		+		+		+	+	+	+	+		+		+		+		+	+	+	+
75	+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+	
76	+		+		+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+
78		+	+				+	+	+	+	+			+	–				+	+	+	+	+			+	+				+	+	+	+	+	
79	+						–		–		–	+	+						–		–		–	+	+						+		+		+	+
80																																				
81							+	+	+	+	+	+							+	+	+	+	+	+							+	+	+	+	+	+
82		+		+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+

Note: We only present statistically significant signs.

Table D.1 (continued…)

	ALL												OECD												nonOECD											
Method	OLS						poisson						OLS						poisson						OLS						poisson					
Sample period (Except for stringency)	2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002	
Exporter: A Importer: B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
83		+		+		+	+	+	+	+	+	+		+		+		+	+	+	–	+	–	+		+		+		+	+	+	+	+	+	+
84		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+
85		+		+		+	+		+		+			+		+		+	+		+		–			+		+		+	+		+		+	
86	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+	+		+		+		+	+	+	+	+	+
87	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	–	+	–	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+
88	+		+		+		+	+	+	+	+		+		+		+		+	+	+	+	+		+		+		+		+	+	+	+	+	
89	+	+	+	+	+		+		+		+		+	+	+	+	+		–		–		–		+	+	+	–	+		+		+		+	
90	+	+		+	+	+	+	+	+	+			+	+		+	+	+	+	+	+	+			+	+		+	+	+	+	+	+	+		
91	–		+		+					–			+		+		+					–			–		–		–					+		
92			–				+		+						–				+		+						–				+		+			
93	+		+				+	+	+	+	+	+	+		+				+	–	+	+	+	–	+		+				+	+	+	+	+	+
94		+		+	+	+	+	+	–	+	–	+		+		+	+	+	–	+	–	+	–	–		+		+	+	+	+	+	+	+	+	+
95	–	+	–	+	–	+							–	+	–	+	–	+							–	+	–	+	–	+						
96	–	+	–	+	–	+	+	+	+	+		+	–	+	+	+	+	+	+	–	+	–		–	–	+	–	+	–	+	+	+	+	+		+
97	+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+		+	

Note: We only present statistically significant signs.

Table D.2 Aggregate level estimations in the case of WEFSTR for 2000 and its components using equation (4) and (5)

	ALL												OECD												nonOECD											
Method	OLS						poisson						OLS						poisson						OLS						poisson					
Sample period (Except for stringency)	2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002		2000		2001		2002	
Exporter: A Importer: B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
WEFSTR	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
overall	+	+	+		+	+	+		+	+	+	+	+	+	+		+	+	+		+	+	+	+	+	+	+		+	+	+		+	+	+	+
leader	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+
cla_sta	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
flex	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
enforce						+	+		+	+	+	+						+	+		+	+	+	+						+	+		+	+	+	+

Note: We only present statistically significant signs.

"Economic Analysis of Linking Domestic Emission Trading Schemes"

Shiro Takeda
(Kantogakuen University and Center for Environment and Trade Research)
Makoto Sugino
(Sophia University and Center for Environment and Trade Research)
Toshi. H. Arimura
(Sophia University and Center for Environment and Trade Research)

Abstract

In recent years, legislation concerned with climate change has been debated in developed countries all over the world. The emission trading scheme is the main policy reducing GHG emissions. However, the difference in the marginal abatement cost due to the difference in the emission reduction rate creates asymmetric costs for firms in different regions. Linking of regional ETS's can level the playing field for regions linked internationally.

In this paper, we simulate the effects of linking regional ETS's on the Japanese economy using a computational general equilibrium model. We find that the marginal abatement cost differs significantly between the six regions with emission reduction targets. The marginal abatement cost converges when the link is conducted. We also find that linking the Japanese domestic ETS is beneficial for the Japanese economy.

Sensitivity analysis is also conducted to test if the results from the base model are robust. The results from the sensitivity analyses verify that the results from the base model are robust. In other words, linking is beneficial for Japan.

1. Introduction

On September 22, 2009, Prime Minister Yukio Hatoyama (Democratic Party of Japan, DPJ) announced that Japan will reduce GHG emission by 25% compared to 1990 levels at the UN Summit on Climate Change. The Japanese government has yet to decide how to reduce emissions by 25% but the manifesto for the DPJ states that the 25% reduction of emissions will be achieved using a domestic emission trading scheme (ETS) and/or carbon tax, i.e. carbon pricing. Thus, the possibility of implementing a carbon tax and/or ETS has risen in Japan.

The Japanese economy has been considered to have a hig energy efficiency compared to other countries, leading to higher marginal costs curves. In addition, the ambitious reduction target will also push the emission reduction costs up. Thus, is predicted that the emission permits will be higher than the emission permits traded in the EU-ETS, if the Japanese government implements a domestic ETS. Furthermore, the high emission permit prices will deteriorate the competitiveness of Japanese firms and have a negative effect on the Japanese economy. To counter this negative effect, designing of the domestic ETS is very crucial.

Preserving the competitiveness of domestic industries s a very political but crucial aspect of implementing a carbon price. Regional ETS's around the globe includes cost containment measures to counter the adverse effect of carbon pricing. The most commonly used method is the usage of offset credits. However, recent ETS designing includes provisions for free allocation of emission permits or rebating carbon costs. These cost containment measures are estimated to lower the compliance cost for specific sectors, but raise the cost of reaching the reduction target for the entire economy.

Another cost containment measure choice for Japan is linking the domestic ETS internationally. Linking ETS's is expected to raise the efficiency of the market and lower the permit price. Thus, the Japanese Economy can benefit from linking the domestic ETS to foreign ETS's because Japan's compliance cost is expected to be lowered by the link.

The manufacturing industries in Japan are very skeptical about the consequences of linking internationally. The argument against linking is that panese wealth will be lost to foreign countries as a result of importing permits from abroad. Thus, the industrial sectors are pushing for an ETS system without linkages with other systems in the future. The environmental NGO's are also against linking of the Japanese domestic ETS. If the Japanese domestic ETS is linked with abroad, Japan will likely be a net buyer of credits. This means that Japan will depend on cheap credits produced in other countries, but Japan itself will not reduce emissions. From the environmental aspect, Japan will not contribute directly to the reduction of GHG's and will be considered as unacceptable from the NGO community.

However, these arguments overlook the economic efficiency of linking ETS's. In other words, as more ETS are linked together, the difference in marginal abatement cost reduces and results in a converged marginal abatement cost and emission permit price. A converged emission permit price can be considered as a leveled playing field for internationally competing firms, at least for countries with emission reduction obligations.

The purpose of this paper is to analyze the effects of linking the Japanese domestic ETS to other regional ETS's. We assume that the linking of the domestic ETS will be in the form of a direct, bilateral, and unrestricted link.

The organization of this paper is as follows. In the next section, the theoretical aspect of linking domestic ETS internationally is reviewed. In section 3, the CGE model is presented along with the simulation scenarios. Section 4 presents the from the CGE model and Section 5 concludes the paper.

2. Linking Domestic Emission Trading Schemes

In this section, we organize the types of international links and then review the barriers for linking internationally. Finally, we organize the present status of international links and look into the possibility of future links based on recent climate change legislation related to ETS's.

2.1. Types of International Links

Domestic emission trading schemes can be linked internationally directly or indirectly. A direct link is where an ETS in one region allows for usage of other ETS's emission permits for compliance. An indirect link is a link where two ETS's are linked directly through the usage of offset credits such as CER (Certified Emission Reduction) or both ETS's links to a third ETS unilaterally.

Furthermore, a direct link can be categorized as a bilateral or unilateral link. A bilateral link is where the emission permit is allowed to be used in both region A and B. This type of link allows for permits to flow freely across borders without any restriction or penalties. Therefore, permit prices in both regions converges to one permit price. On the other hand, a unilateral link is where region A allows the inflow of permits from regio , but not vice versa.

Furthermore, there are two types of linking concerning the scope of linkage. First, there is the unrestricted link, where there is no limitation in the usage of emission permits. Second, the restricted link is where the system allows a limited amount of permits to enter or leave the domestic system.

2.2. Barriers for International Links

When linking internationally, the significant barriers confronting the linkage needs to be worked out before the linkage becomes possible. Tuerk et al. (2009) organizes potential barriers that may arise when domestic ETS's links internationally into two groups; easy to harmonize and difficult to harmonize. They list five potential barriers that are very critical for the link to be completed.

First, stringency of the target within the ETS is a possible barrier. If there is an international agreement such as the Kyoto Protocol, the level of the national target does not create unfair burden between nations because nations ratify the international treaty independently. However, the domestic ETS's are arranged domestically, therefore the coverage of the ETS and the reduction target within the ETS differs significantly across countries. For example, the EU-ETS covers approximately 40% of total emission whereas, the pending US legislation, American Clean Energy and Security Act of 2009 (ACES, HR 2454), covers approximately 85% of the economy. This difference in the coverage and the stringency of the target is critical because the burden of each country is determined by these two factors. In other words, the net seller of permits will be the country with the wider coverage and less stringent target. Thus, the burden of reducing emission must be agreed beforehand.

Second, the stringency of domestic enforcement is a po e barrier. The enforcement of laws and regulations is critical in linking ETS's because the stability of the carbon market depends on governance of each country. Linking with systems in countries where political stability is not secured is expected to lower permit prices due to the to take compatible enforcement measures. However, this can be considered a small problem when OECD countries link internationally.

Third, offset credit provisions within the ETS create a significant barrier for linking. The Kyoto Protocol allows for the usage of Kyoto credits, which is internationally acceptable. Thus, if the offset used within the ETS are CER or ERU credits (i.e. Kyoto credits), then the link will be easily achieved. However, if one ETS allows for REDD and/or land use credits that are not internationally acceptable, then it will create a significant barrier. For example, ACES allows credits from the agricultural sector and REDD credits within the domestic ETS. On the other hand, the European Commission does not accept these types of credits within the EU-ETS. Thus, linking the two systems will be difficult without the resolution of the offset credit problem.

Fourth, the type of target the ETS sets also generates difficulties in linking. There are two types of targets within the ETS; absolute and intensity target. The absolute target or cap-and-trade type of target regulates the emission volume entirely. On the other hand, the intensity target regulates the per output emission level. The total emission of each facility/firm depends upon the output level. In other words, it is uncertain if actual emission reduction occurs because the improvement of emission intensity may be cancelled by the increase in production. This, uncertainty is expected to destabilize the market if one system uses a cap-and-trade approach and the other intensity approach, due to the difference in the quality of the emission permit traded.

Finally, the cost-containment measure imposed by each ETS will cause difficulties. Cost containment measures include free allocation of permits, price cap, and banking and borrowing of permits. Free allocation of permits in one ETS that covers more industries will result in symmetric treatment of the same industry across borders. Thus, the unfair treatment will become a barrier of linking ETS's. A price cap is a cap on the price of the permit predetermined by the government. When the price reaches the price cap, the government supplies unlimited amounts of permits. If permit prices in both ETS's rises above the price cap, arbitrage trading of permits will occur. In other words, firms will buy the unlimited supplied permits from the ETS with a price cap and sell them in the system without the price cap. As a consequence, the price falls until the price equals the price cap. This means that both systems will have a price cap. The rules for banking and borrowing also create difficulties. Banking of permits will not create a severe barrier for linking because many systems allow banking of credits for future usage. However, borrowin is a crucial matter that needs to be resolved beforehand. If the rules for borrowing are very loose, then future abatement cost may increase and/or the reduction level may be lowered to ce the compliance costs. Thus, linking will be difficult if the borrowing rules are not compatible.

2.3. Present Status and Future Possibility of International Links

Presently, the EU[1], US, Australia, New Zealand, Canada and Japan are preparing the nationwide ETS. Here, we will focus on the EU-ETS and the pending US legislation.

The EU-ETS is the only active nation/region wide ETS in the world. Presently, the EU-ETS is in the second phase (2008 to 2012) and covers approximately 40% of total emission in the EU. The maximum amount of credit use in the second phase is 13.5% of total emission reduction. The Kyoto Protocol states that the use of offset credits must be supplemental to domestic reduction. Thus, the EU regulates offset credits usage within the EU-ETS to keep credit usage supplemental.

The European Commission announced the "EU Climate Change and Energy Package" in 2008, including the provisions for the third phase of program. In the "EU Climate Change and Energy Package", the EU27's post-Kyoto target was set at a 20% reduction from 1990. It also stated that EU27 is willing to reduce their emissions by 30%, if an international agreement was reached for 2020. The aggregate import limit of credits is estimated as of the aggregate cap from 2008 to 2020 (Baron et al., 2009).

The provision also added that the usage of CER credits should not exceed 50% of total emission reduction when the target was raised to a 30% reduction. As a result, the total amount of

1 EU is presently in the second phase of the EU-ETS. The debate in the commission is the designing of the EU-ETS in the third phase starting from 2013.

credit usage from 2008 to 2020 will be from 1.6 to 1.9 Gt-CO_2.[2]

The ACES of the US also includes provisions on credit Unlike the EU-ETS, the offset credits available in the ACES include a wide variety of non-Kyoto credits.[3] The annual maximum amount of offset credits available for use is Gt-CO_2. This figure includes both domestic and foreign offset credits. The ratio is 50% domestic 50% foreign credits. However, the foreign offset credits must pass one of the two conditions to be accepted within the US. First, the offset credits must originate from a country that is a part of the same international treaty which the US ratifies. Second, if the director of the EPA allows the usage of the credits. Similarly, the Kelly-Boxer bill has provisions for offset credits. The maximum an credit is 2 Gt-CO_2, but the domestic to foreign ratio differs from ACES. The domestic offset credits are limited to 1.5 Gt-CO_2, compared to ACES's 1.0 Gt-CO_2. The foreign credits are limited to 0.5 Gt-CO_2.

The European Commission has announced the road map for a future international ETS. The first step of the international link is among OECD countries by 2015. Then, the internationally linked ETS will be extended to cover newly industrialized countries such as China and India by 2025. Finally, the link is expected to cover the entire globe by 2030. However, currently, the EU-ETS is the only region-wide cap-and-trade system. Thus, in the short-run, the international linkage will be based on CDM's and other types of offset credits. Therefore, the link can be defined as a restricted indirect link between regional ETS's.

3. Model Specification and Simulation Scenarios

In this section, the model characteristics are briefly presented, followed by the simulation scenarios. There are three sets of simulations scenarios; linking ETS's with variable labor supply, linking ETS's with fixed labor supply and linking ETS's with labor tax cuts. All of the simulation scenarios assume that the link is an unrestricted bilateral direct link.

3.1. Model Specification

We revise the multi-region, multi-sector GTAP-EG model (Rutherford and Paltsev, 2000 and Fischer and Fox, 2007) to simulate the effects of g regional ETS internationally. This model is a static Computational General Equilibrium model (CGE model), implying that capital, land, and natural resources remain constant. Furthermore, this model does not include technological progress and new renewable energy. Thus, this model has a very simple structure. We use this simple

---

2 Facilities outside of the EU-ETS are allowed to use 1.1 to 1.3 Gt-CO_2 credits from the 2008 to 2020 time span.

3 Kyoto credits refer to credits produced by the Clean Development Mechanism and Joint Implementation.

structured model because the results can be easily interpreted compared with other models.

The data used in the simulation is from the GTAP7 database. The original GTAP7 data has 117 countries/regions and 57 industrial sectors. We aggregate the original GTAP7 data into 18 regions with 26 industries/commodities to avoid computational complexities. The 18 regions and 26 industry/commodity are listed in Table 1 and Table 2, respectively.

Each sector has a multi-nested CES production function. The energy sector, agricultural sector and non-energy sector has a different production function structure. The energy sector (i.e. coal, petroleum, and natural gas) has three types on inputs: labor, capital, and natural resources. Natural resources are included for the energy sector because production of fossil fuels is restricted by the amount of natural resources. The agricultural sector has labor, capital and land as input factors. Here, land is a specific factor for the agricultural sector. The energy sector and agricultural sectors has a sector specific factor, however, the non-energy sector does not include natural resources or land because other sectors do not need these industry factors to produce their commodities.

The final demand is depicted by one representative household in each region. The household maximizes utility composed by consumption of goods and services and leisure subject to the budget constraint. Thus, the household decides the amount of labor supplied endogenously. Previous models incorporating the leisure-labor structure uses estimated substitution of elasticity from the US (for example Fischer and Fox, 2007). Here, we estimate the substitution elasticity for Japan and uses this figure for Japan (0.73). This model specification lowers the adverse effect of an environmental policy, i.e. carbon pricing.

The government has a variety of tax revenues and uses revenues to consume various goods and services. The model used here does not include the budget deficit for each country. Therefore, the tax revenues are not used to balance the national budget deficit.

We assume an economy-wide cap-and-trade ETS for each country subject to an emission reduction target. We also assume that the rules for allocating the emission permits is auctioning. The revenues from auctioning of permits are directly transferred from the government to the household by lump-sum. The world is linked by international trade of goods.

3.2. Countries Reducing Emission and Emission Reduction Target

Table 3 shows the emission reduction rate submitted to the UNFCCC by January 31, 2010 for Annex I countries. There are two problems concerned with the reduction rates: baseline year and emission reduction rate. The baseline year differs among countries. For example, Japan and EU sets 1990 as the baseline year whereas, the US and Canada sets 2005 as the baseline year. In addition, many countries have emission reduction rates that are conditional. For example, the Japanese reduction target is a conditional 25% reduction. The specified condition is that the reduction rates be fair and effective international framework where all major economies participate. Another example is the EU reduction rate, which is an unconditional 20% reduction, but if developed countries agree to a post-Kyoto treaty, then the target will be raised to a 30% ction. Other countries have conditions linked with monetary aid and technological transfer.

We overcome these two problems by recalculating the emission reduction rate with the same baseline year and use the highest value for the reduction rate region. First, we assume that all of the condition for raising the reduction rates are cleared and use the highest value listed in Table 3 for each country. Second, the targets are recalculated using 2005 as the baseline year. The converted emission reduction rates are listed in Table 4. We assume that the emission reductions are imposed on six regions; Australia, Canada, EU, Japan, New Zealand and the US. We use 2005 as the baseline year because the GTAP7 data uses 2004 as the baseline year. Using 2005 as the baseline has a potential shortcoming. However, the 2004 and 2005 emission levels are similar for each country. Thus, using 2005 as a baseline year does not create a large problem in the simulation.[4]

3.3. Simulation Scenarios

First, we estimate the impact of the regional cap-and-trade ETS for countries that have quantitative reduction targets for 2020 (Scenario BL). In other words, EU, US, Canada, Australia, New Zealand and Japan reduce emissions according to Table 4. This is the baseline case, where all of the countries act uncooperatively. Since there is no international link in this case, the permit price is expected to differ among regions. In other words, the marginal abatement cost for each region is different.

Next, we compare three scenarios to examine the effects of linking the Japanese domestic ETS internationally. In scenario 1, S1, each region are linked internationally with other ETS's. S1 assumes that the international link is completed with reduction regions cooperating. In this scenario, the OECD-wide link which the European Commission is trying to accomplish by 2015.

Scenario 2, S2, is where US and Canada does not link internationally but the other four regions links internationally. The US is not interested in linking with other ETS, because the US does not want US industries to bear the burden of increased carbon costs. In addition, Canada will not link internationally if the US does not link, because of the close ties with the US. Thus, S2 can be considered to illustrate the short term international linkage.

In scenario 3, S3, the international link is conducted without the participation of Japan. The manufacturing sectors in Japan are against the linking of the Japanese domestic ETS internationally. Their logic is that international linking will result the loss of Japanese national wealth. Furthermore, the environmental NGO's are also skeptical of linking the ETS internationally

[4] The reduction rate for each country includes six types of GHG's including CO_2. In this model, only the CO_2 emitted from fossil fuel combustion is covered. Therefore, process emissions and emissions of other GHG's are not included. Thus, the accuracy of the reduction rate is lost due to the data available.

because linking reduces the domestic effort. This case can be considered to reflect the domestic resistance against linking the Japanese domestic ETS to other ETS’s.

3.4. Sensitivity Test

Other than the linking scenarios discussed above, we test if the results are robust by simulating each scenario without the leisure-labor specification for the household. In other words, we change the model to reflect the fixed labor supply. For each of the four scenarios, BL and S1 to S3, we test to see the difference in the results (FBL, FS1, FS2, FS3).

Another sensitivity analysis we conduct is the treatment of the auction revenue. The labor tax is known to distort the labor market, i.e. lower labor supply. If the revenue from auctioning the emission permits is used to replace labor tax, the distortion of the labor market is expected to be reversed. We simulate BL, S1, S2 and S3 using the altered model specification (LBL, LS1, LS2, LS3).

Table 5 summarizes the simulation scenarios estimated in the analysis.

4. Simulation Results

In this section, the results from the simulation are presented. First, the results for the permit price and trade volume are presented for scenarios BL, S1, S2 and S3. Next, we present the results for the BL, S1, S2 and S3 case for the Japanese economy. Finally, we will present the results from the sensitivity analysis.[5]

4.1. Permit Price and Trade Volume (BL, S1, S2 and S3)

Table 6 shows the price of permits and the purchasing rate of permits from abroad for the baseline simulation. The domestic permit price is estimated to be the high for New Zealand ($154 /t-$CO_2$), Japan ($115 /t-CO_2), and EU27 ($90 /t-$CO_2$) reflecting the high marginal abatement cost. On the other hand, the US ($24 /t-$CO_2$) and Canada ($25 /t-CO_2) are expected to have low permit prices. The no link case, BL, shows that the permit price will differ between countries. However, the permit price converges to one single price for countries linked internationally in the linking cases, i.e. S1, S2, and S3.

In S1, the permit price is expected to be $44. Japan, EU27, and New Zealand are net buyers of permits, with demand for permits of 164 Mt-CO_2, 415 Mt-CO_2, and 8 Mt-CO_2,

[5] The main focus of this paper is the effect of linking ETS's on the Japanese economy. Thus, the results presented here are those concerned with Japan such as the price of emission permits and the volume of emission permits purchased. The results for vailable on request.

respectively. Thus, EU27 and Japan will be the main players on the d side. The suppliers of permits are expected to be Australia (15 Mt-CO_2), US (525 Mt-CO_2) and Canada (47 Mt-CO_2). This implies that the US will be the main supplier of permits.

As for S2, the permit price in the linked regions, i.e. Japan, EU27, Australia and New Zealand, the permit is approximately \$90 /t-CO_2. The permit price compared to the no link case is lower for both Japan and New Zealand but higher for Australia. Interestingly, in this scenario, the EU27's permit price does not change drastically. This because EU27's marginal abatement cost is similar to the marginal abatement cost in the linked system. Thus, the net trade is zero for EU27, resulting in the single demand of permits from Japan, whereas the seller will be Australia.

The S3, Japan does not link case, results shows that t permit price will remain high for Japan (115 /Mt-CO_2) but low for the other linked countries (\$40 /t-CO_2). In this case, Japan will not link internationally resulting in EU27 being the net buyer (470 Mt-CO_2) and the US being the net supplier (431 /Mt-CO_2).

Turning to the domestic reduction volume, the net buyers of permits reduce their actually domestic emission reduction because their can purchase cheaper permits from the international market. For example, the Japanese reduction volume is 402 Mt-CO_2 with and without the link. However, Japan will purchase approximate 10% to 40% of the reduction volume from the international market if there is an international link (S1 and S2). On the other hand, a country that becomes the net supplier of permits increases the domestic reduction rate. For example the US increases the reduction rate by 40% to 50% when the US links internationally. This result verifies that the US domestic marginal abatement cost will increase because of the link. Thus, from the political point of view, linking internationally will be a very difficult decision.

4.2. The Effects of Linking on the Japanese Economy (BL, S1, S2 and S3)

Table 7 shows the results from the simulation concerni g the Japanese economy. The welfare of Japan due to the implementation of a 25% reduction compared with 1990 is estimated to be -0.67%. The reduction of welfare is reduced to -0.38% to -0.59%. The reduced averse effect of reducing emissions is the effect of linking internationally. The reduced price due to the link lowers the marginal abatement cost within Japan. This lowers the burden of the Japanese industries which in turn does not increase the price of commodities. Since the commodity price does not increase as much, the wage rate does not drop as compared to the no link case. The conserved wage rate allows consumption to stay at a higher level. Thus, the welfare level does not decrease as much as the no link case when the ETS is linked internationally.

Similarly, the effects of linking ETS's reduces the entire burden on the Japanese economy. The loss of GDP is reduced from 1.04% to 0.32% in S1 and 0.77% in S2. This implies that even though Japan will be a net buyer of permits and money from Japan will flow abroad, the loss in GDP will be modest. Therefore, linking internationally is very important if the Japanese government decides that conserving GDP is the most important policy objective.

4.3. Sensitivity Analysis

Table 8 summarizes the results from the two sensitivity analyses. Compared with the results in Table 7, the results in Table 8 shows slight differences. For example, the decrease in welfare is greater in the fixed labor supply case, FBL, FS1, FS2 and FS3, than the results from the variable labor supply case. However, impact of linking ETS's is the smallest in the FS1, the complete link case, while the impact is the greatest in the FBL and FS3, the no link case.

The results for the labor tax reduction simulation also shows similar results as the fixed and variable labor supply case. In other words, the impact of the carbon policy is the smallest in the complete link case, LS1, and the highest for the no li BL and LS3. Interestingly, the results in this model specification reveals that the Japanese can become positive if the revenue from auctioning the permits is used to reduce the labor tax already in place.

5. Conclusion

The European Commission announced that they would like to link internationally starting with OECD countries by 2015 and moving towards a world-wide link by 2030. One benefit of linking internationally is the leveling of the playing field for countries with emission reduction targets. The different emission reduction target that each country pledged to the UNFCCC in January 2010 suggests that the level of emission reduction will differ greatly among Annex I countries. Differences in emission reduction targets will directly appear in the emission permit prices if each country covers the entire economy with an cap-and-trade type emission trading scheme. However, the link will close the differences in the marginal abatement cost, meaning that the permit price will converge to a single price. Thus, the condition of competition between firms in countries that has linked internationally will not be affected by the implementation of a stringent emission reduction target.

In this paper we simulated the impacts of linking emission trading schemes. We focused on the relevant results concerning the Japanese economy such as emission permit prices, welfare and GDP before and after linking internationally.

From the analysis, it was revealed that Japan will benefit from linking internationally because the marginal abatement cost for Japan is relatively higher than other countries with emission caps. Thus, one of the domestic resistance against linking i nationally is not rational, because there is more benefits than costs from linking. The results from the sensitivity analysis also revealed that participating in the international link was beneficial for Japan.

In the simulation, we focused on a complete multi-lateral direct linking. However, in reality, the linkage between regional ETS would be more likely to arise indirectly through the usage of CDM and other offset credits.

Future research areas includes the disaggregation of the data, including the CDM in the model, and modeling the sectoral crediting mechanism. These model aspects are very important in understanding the impacts of international linking using indirect methods. This is left for future research.

Reference

Baron, R., Buchner, B. and Ellis, J. (2009) "Sectoral approaches and the carbon market," OECD/IEA.

Fischer, C. and Fox, A. K. (2007) "Output-Based Allocation of Emission Permits for Mitigating Tax and Trade Interactions," Land Economics, Vol. 83, No. 4, pp. 575-599.

Hertel, T. W. ed. (1997) Global Trade Analysis: Modeling and Applications, New York: Cambridge University Press.

Rutherford, T. F. and Paltsev, S. V. (2007) "GTAPinGAMS and GTAP-EG: Global Datasets for Economic Research and Illustrative Models," September, Working Paper, University of Colorado, Department of Economics.
(available at: http://debreu.colorado.edu/gtap/gtapgams.html)

Tuerk, A., Mehling, M., Flachsland, C., and Sterk, W.(2009) "Linking carbon markets: concepts, case studies and pathways," Climate Policy, Vol 9. pp341-357.

Figures and Tables

Table 1: List of Regions

	Regions	
	Abr.	Explanation
1	JPN	Japan
2	EUR	European Union 27, EU27
3	AUS	Australia
4	NZL	New Zealand
5	USA	United States of America
6	CAN	Canada
7	CHN	China
8	KOR	South Korea
9	TWN	Taiwan
10	IND	India
11	ASI	Asia
12	BRA	Brazil
13	OSA	Central and South America
14	OEU	Other European Countries
15	RUS	Russia
16	FSU	Other Former Soviet Union
17	MPC	Mexico and OPEC
18	ROW	Rest of the World

Table 2: List of Industries

	Industries	
	Abr.	Explanation
1	COL	Coal
2	OIL	Crude oil
3	GAS	Natural gas
4	AGR	Agriculture
5	FSH	Fishery
6	OMN	Other mineral mining
7	FPR	Food products
8	SGR	Sugar
9	TWL	Textiles-wearing apparel-leather
10	LUM	Wood and wood products
11	PPP	Paper, pulp, print
12	P_C	Petroleum and coal products
13	CRP	Chemical products
14	NMM	Non-metallic minerals
15	I_S	Iron and Steel
16	NFM	Non-ferrous metals
17	TRN	Transport equipment
18	OME	Other machinery
19	OMF	Other manufacturing
20	ELY	Electricity
21	CNS	Construction
22	TRD	Trade, wholesale and retail
23	OTP	Land Transport
24	WTP	Water Transport
25	ATP	Air Transport
26	SER	Services

Table 3: Emission Reduction Targets

Country	Base Year	Unconditional Target	Conditional Target	Condition
Australia	2000	-5%	-15% or -25%	Global reduction agreement including developing countries or ambitious global deal to stabilize atmospheric GHG concentration below 450 ppm.
Belarus	1990	-	-5% to -10%	Access of Belarus to the Kyoto flexible mechanisms, intensification of technological transfer etc.
Canada	2005	-	-17%	Aligned with the final economy wide emission target of the US.
Croatia	1990	-5%	-20% or -30%	Accession of Croatia to the EU.
EU27	1990	-20%	-30%	Developed countries commit to comparable emission reductions and developing countries contribute adequately according to their responsibilities and respective capabilities.
Iceland	1990	-	-30%	Developed countries commit to comparable emission reductions and developing countries contribute adequately according to their responsibilities and respective capabilities.
Japan	1990	-	-25%	Premised on the establishment of a fair and effective international framework in which all major economies participate and on agreement by those economies on ambitious targets.
Kazakhstan	1992	-15%	-	-
Liechtenstein	1990	-20%	-30%	Developed countries commit to comparable emission reductions and developing countries contribute adequately according to their responsibilities and respective capabilities.
Monaco	1990	-	-30%	Access of Monaco to the Kyoto flexible mechanisms, etc.
New Zealand	1990	-	-10% to -20%	Global reduction agreement including developing countries, rules for LULUCF, etc.
Norway	1990	-30%	-40%	Major emitting Parties agree on emissions reductions in line with the 2 degrees Celsius target.
Russian Federation	1990	-	-15% to -25%	Appropriate accounting of the potential of Russia's fo estry and all major emitters the legally binding obligations to reduce anthropogenic GHG emissions.
Switzerland	1990	-20%	-30%	Developed countries commit to comparable emission reductions and developing countries contribute adequately according to their responsibilities and respective capabilities.
Ukraine	1990	-	-20%	Agreed position of the developed countries on quantified emissions reduction targets, keep the status of Ukrain as a country with economy in transition, keep the existing lexible mechanisms of the Kyoto Protocol, etc.
United States of America	2005	-	-17%	Conformity with anticipated U.S. energy and climate legislation, recognizing that the final target will be eported to the Secretariat in light of enacted legislation.

Table 4: Emission Reduction used in the Simulation

	Baseline Year	UNFCCC Reduction Rate %, From Baseline Year)	Reduction Rate %, Baseline Year)	Reduction Rate %, 2005)	CO2 Emission, Model Estimation 2004、MtCO2)	Reduction Volume MtCO2)
JPN	1990	25	25	33.4	1,205	402
EUR	1990	20-30	30	32	3,962	1,268
AUS	2000	5-25	25	31.4	354	111
NZL	1990	10-20	20	43.5	35	15
USA	2005	17	17	17	6,068	1,032
CAN	2005	17	17	17	566	96

Table 5: Summary of Simulation Scenarios

Scenario	Explanation
BL	No international link.
S1	6 regions link internationally.
S2	4 regions link internationally. US and Canada does not join.
S3	5 regions link internationally. Japan does not join.
FBL	No international link with fixed labor supply.
FS1	6 regions link internationally with fixed labor supply.
FS2	4 regions link internationally with fixed labor supply. US and Canada does not
FS3	5 regions link internationally with fixed labor supply. Japan does not join.
LBL	No international link with labor tax cut.
LS1	6 regions link internationally with labor tax cut.
LS2	4 regions link internationally with labor tax cut. US and Canada does not join.
LS3	5 regions link internationally with labor tax cut. Jap oes not join.

Table 6: Simulation Results

Scenario		JPN	EUR	AUS	NZL	USA	CAN
BL	Reduction Volume (Mt)＝A	402.5	1267.8	111.1	15.0	1031.5	96.2
	Price of Emission Permits ($/t)	115.5	90.4	35.3	154.2	24.2	25.4
	Domestic Reduction Volume (Mt)	-402.5	-1267.8	-111.1	-15.0	-1031.5	-96.2
	Volume of Purchased Permits (Mt)＝B	0	0	0	0	0	0
	Amount of Purchased Permits ($1 billion)	0	0	0	0	0	0
	Purchase Rate(%)＝B／A	0	0	0	0	0	0
S1	Reduction Volume (Mt)＝A	402.5	1267.8	111.1	15.0	1031.5	96.2
	Price of Emission Permits ($/t)	44.4	44.4	44.4	44.4	44.4	44.4
	Domestic Reduction Volume (Mt)	-238.1	-852.8	-126.2	-7.3	-1557.0	-142.8
	Volume of Purchased Permits (Mt)＝B	164.4	415.1	-15.1	7.8	-525.5	-46.7
	Amount of Purchased Permits ($1 billion)	7.3	18.4	-0.7	0.3	-23.3	-2.1
	Purchase Rate(%)＝B／A	40.8	32.7	-13.6	51.6	-50.9	-48.5
S2	Reduction Volume (Mt)＝A	402.5	1267.8	111.1	15.0	1031.5	96.2
	Price of Emission Permits ($/t)	89.6	89.6	89.6	89.6	24.2	25.4
	Domestic Reduction Volume (Mt)	-354.5	-1262.5	-168.2	-11.3	-1031.5	-96.2
	Volume of Purchased Permits (Mt)＝B	48.0	5.3	-57.0	3.7	0	0
	Amount of Purchased Permits ($1 billion)	4.3	0.5	-5.1	0.3	0	0
	Purchase Rate(%)＝B／A	11.9	0.4	-51.3	24.8	0	0
S3	Reduction Volume (Mt)＝A	402.5	1267.8	111.1	15.0	1031.5	96.2
	Price of Emission Permits ($/t)	114.8	40.2	40.2	40.2	40.2	40.2
	Domestic Reduction Volume (Mt)	-402.5	-798.3	-119.8	-6.7	-1462.8	-134.1
	Volume of Purchased Permits (Mt)＝B	0	469.5	-8.7	8.3	-431.3	-37.9
	Amount of Purchased Permits ($1 billion)	0	18.9	-0.3	0.3	-17.3	-1.5
	Purchase Rate(%)＝B／A	0	37.0	-7.8	55.2	-41.8	-39.4

Table 7: Effects of International Link on the Japanese Economy

JPN	BL	S1	S2	S3
Permit Price ($/t)	115.5	44.4	89.6	114.9
Domestic Reduction Volume (Mt)	-402.0	-238.0	-354.0	-402.0
Domestic Reduction Rate (%)	-33.4	-19.8	-29.4	-33.4
Volume of Purchased Permits	0	164.4	48.0	0
Amount of Purchased Permits ($1 billion)	0	7.3	4.3	0
Welfare (%)	-0.67	-0.38	-0.59	-0.67
GDP (%)	-1.04	-0.32	-0.77	-1.03
Consumption (%)	-1.63	-0.80	-1.38	-1.63
Export (%)	-4.22	-1.11	-3.00	-4.12
Import (%)	-4.02	-2.39	-3.63	-3.95
Terms of Trade (%)	1.11	0.50	0.84	1.15
Labor Supply (%)	-0.56	-0.12	-0.38	-0.55
Wage Rate (%)	-2.75	-1.21	-2.24	-2.74

Table 8: Results from the Sensitivity Analysis

JPN	FBL	FS1	FS2	FS3	LBL	LS1	LS2	LS3
Permit Price ($/t)	117.3	45.1	91.0	116.7	120.8	45.7	92.8	120.2
Domestic Reduction Volume (Mt)	-402.0	-240.0	-355.0	-402.0	-402.0	-239.0	-354.0	-402.0
Domestic Reduction Rate (%)	-33.4	-19.9	-29.5	-33.4	-33.4	-19.8	-29.4	-33.4
Volume of Purchased Permits (Mt)	0	163.0	47.0	0	0	164.0	49.0	0
Amount of Purchased Permits ($1	0	7.3	4.3	0	0	7.5	4.5	0
Welfare (%)	-1.07	-0.68	-1.00	-1.07	-0.36	-0.27	-0.36	-0.37
GDP (%)	-0.71	-0.26	-0.55	-0.71	-0.10	0.02	-0.05	-0.10
Consumption (%)	-1.07	-0.68	-1.00	-1.07	0.00	-0.21	-0.14	0.00
Export (%)	-4.01	-1.08	-2.86	-3.91	-3.58	-0.85	-2.47	-3.48
Import (%)	-3.81	-2.36	-3.49	-3.73	-3.38	-2.15	-3.13	-3.29
Terms of Trade (%)	1.05	0.49	0.80	1.10	0.95	0.44	0.71	1.00
Labor Supply (%)	0.00	0.00	0.00	0.00	1.07	0.47	0.86	1.07
Wage Rate (%)	-3.00	-1.28	-2.42	-2.98	1.04	0.17	0.64	1.04

Optimal Strategic Regulations in International Emissions Trading under Imperfect Competition

Tsung-Chen Lee, Hsiao-Chi Chen, and Shi-Miin Liu*

Abstract

This paper analyzes governments' strategic regulations in an imperfectly competitive market of international emissions trading (IET). Whether and how governments intervene in IET is explored. If regulations are decided, it is optimal for price-influencing countries to subsidize but for price-taking countries to tax permit trading. Conducting simulations of the Annex-1 emissions trading, we discover that no-intervention of all countries cannot be supported by any equilibrium. In contrast, all or some countries would regulate at equilibrium. In the latter case, price-influencing countries would not regulate but price-taking countries would. This justifies the necessity of considering no-intervention as a policy choice, and shows that a country's decisions about strategically regulating IET may be affected by other countries' intervention resolutions.

Keywords: international emissions trading, imperfect competition, strategic regulation, strategic trade policy

JEL Classification: Q54,Q58

*Department of Economics at National Taipei University. The corresponding author is Tsung-Chen Lee with the e-mail address of tclee@mail.ntpu.edu.tw.

1 Introduction

An emerging market of carbon emissions trading has expanded the dimensions of international trade and become increasingly prominent in recent years. This market originates from the flexible mechanism of international emissions trading (hereafter IET) proposed by the Kyoto Protocol and intends to lower the Annex-1 countries' compliance costs under given abatement targets. Earlier works show that IET is cost-effective based on an idealistic presumption of no distortion in the market (e.g., Evans, 2003; Criqui et al., 1999; Kainuma et al., 1999; Weyant, 1999; Rose and Stevens, 1993). Nevertheless, realizing possible market distortions due to imperfect competition challenges the cost-effectiveness of IET. Westskog (1996) pioneers this research in providing a theoretical foundation for the relationship between market power and efficiency loss in the IET market. Afterward many ensuing studies analyze the impact of Russian Federation's market power due to hot air (e.g., Bohringer et al., 2007; Klepper and Peterson, 2005; Bohringer and Loschel, 2003; Persson and Azar, 2003; Sager, 2003).

Inspired by literature on strategic trade policy (hereafter STP)[1], this paper tries to explore potential distortions of IET caused by governments' strategic interventions. Because individual countries generally design their climate policies from the perspective of self-interests, strategic IET regulations might be appealing. The regulations could reduce individual Annex-1 countries' compliance costs under the Kyoto targets by shifting the costs from domestic to foreign firms. Also, the regulations could work well in practice; given that the Protocol does not clearly define the Annex-1 countries' trading levels, and that both the Protocol and WTO (World Trade Organization) impose no restriction on governments' regulations in IET. Under the circumstance, one country's regulation could influence other participants, as well as trading efficiency of the IET market. Countries ignoring strategic regulations may suffer from biased predictions about the trading results. Accordingly, this study aims to contribute to IET by analyzing governments' incentives of active-intervention from the strategic "cost-shifting" perspective, and to STP by showing the extent to which its concepts can be applied.

[1]Strategic trade policy is an important topic in international economics. Relevant literature usually focuses on government's intervention policy that could affect firms' interactions in an international oligopolistic market. The policy's central idea is to shift profits from foreign to domestic firms, i.e., a strategic profit-shifting policy. Early contributors in this field include Brander and Spencer (1981, 1984, 1985), Spencer and Brander (1983), Dixit (1984), Krugman (1984), Brander (1986), Eaton and Grossman (1986), etc.

Hwang and Schulman (1993) is the first STP work to investigate governments' incentives of active-intervention. They demonstrate that no-intervention is more probable to occur if it is explicitly considered as an instrument compared to if a regulating instrument (e.g., tax/subsidy or quota) and its level are determined simultaneously. Hence in addition to active-intervention, we regard no-intervention as a policy choice too. Our sequential game of strategic regulations in IET is as follows. Governments first decide whether to regulate emission permit trading and optimal regulating degrees if intervention is adopted. Then price-influencing and price-taking firms select their emission levels in order. Similar to STP's literature, we assume that the IET market is imperfectly competitive. However, unlike studies on STP, countries' statuses of importing or exporting emission permits are endogenously determined in our model. Moreover, we consider both price-influencing and price-taking countries in IET.

If intervention is adopted, the optimal cost-shifting policies for price-taking countries are to alter permit prices in a desired direction since firms' marginal abatement costs equal permit prices at equilibrium without regulation. Imposing tax would induce the desired change. On the other hand, for countries with market power, the best cost-shifting policies are to expand permit trading volumes because these permit buyers (sellers) have marginal abatement costs greater (smaller) than permit prices at equilibrium without regulation. Subsidies would induce the desired effect of enlarging permit trading amounts although the policies also lead to an undesired minor impact on permit prices.

Next, our game-theoretical model is applied to the Annex-1 emissions trading. The purpose is to provide more real-world insights into governments' decisions about regulating or not and into the impacts of regulating policies on trading efficiency. First, we observe that the total trading efficiency is maximized when all price-influencing countries intervene and all price-taking countries do not. That is because subsidizing policies adopted by the price-influencing countries promote permit trading and mitigate efficiency loss caused by imperfect competition. In contrast, taxing policies employed by the price-taking countries impede permit trading and result in higher efficiency loss. With respect to whether to regulate IET, our numerical findings display that no-intervention of all countries is not supported by any equilibrium. Instead, all or some countries regulate at equilibrium. This outcome demonstrates the necessity of including no-intervention in the policy choice set. Finally, equilibrium could occur at the lowest level of total trading efficiency, but not at its highest level.

Westskog (1996) considers no government's intervention when exploring the relationship between market power and efficiency loss in imperfectly competitive IET. Our study extends this work by exploring governments' incentives of active-intervention. Rehdanz and Tol (2005) explicitly examine regulating issues for the allowance-importing country (e.g., tariff and quota) in a two-country model with perfectly competitive IET. Our study supplements to their work by considering allowance importers and exports in a multi-country model with imperfectly competitive IET. On the other hand, some research on STP is also pertinent. Brander and Spencer (1985) exhibit governments' incentives to subsidize international oligopoly industries for exporting (and price-influencing) countries. In contrast, our optimal subsidizing policies apply to both price-influencing importers and exporters under active-intervention. At some of our equilibria, price-influencing countries do not intervene, and price-taking countries impose taxes. Furthermore, our numerical results show that no-intervention of all countries will not appear at any equilibrium, while it could be equilibrium in Hwang and Schulman's (1993) study.

The remainder of this paper is organized as follows. Section 2 describes basic settings of our model. Section 3 analyzes optimal strategic regulations in IET. Section 4 provides a numerical application to the Annex-1 emissions trading. Finally, conclusions are drawn in Section 5.

2 Basic Setting

Consider an imperfectly competitive IET market consisting of $N(\geq 2)$ countries and an agreed allocation of emission caps among them. Denote $\overline{w}_i$ the exogenous emission cap assigned to country i, $i = 1, \ldots, N$. Each country has a representative firm that discharges carbon emissions. For individual firms, the emission caps can be achieved by self-abatement. Let $C_i(e_i)$ be firm i's abatement cost function associated with emitting e_i, $e_i \geq 0$. Assume that firms' marginal abatement costs, $-C_i^{'}(e_i)$, are positive and increasing, i.e., $C_i^{'}(e_i) < 0$ and $C_i^{''}(e_i) > 0$ for all $e_i \geq 0$ and $i = 1, \ldots, N$. Firms could also meet their emission caps by trading permits under price p in the IET market. Firm i's trading amount equals the difference between its emission level e_i and emission cap $\overline{w}_i$. If $e_i > (<) \overline{w}_i$, firm i purchases (sells) emission permits. Accordingly, $(e_i - \overline{w}_i)$ represents firm i's excess demand for permits. Firms having positive (negative) excess demand are permit buyers (sellers).

When firms trade in the IET market, governments could choose to intervene or not to intervene. Under the former situation, governments need to decide their taxing or subsidizing levels on permit trading. Denote t_i government i's taxing or subsidizing level. If the firm is a permit buyer, $t_i > (<) 0$ means that its purchases are taxed (subsidized). If the firm is a permit seller, $t_i > (<) 0$ implies that its sales are subsidized (taxed). Finally, $t_i = 0$ signifies zero tax or subsidy. A policy with positive t_i suggests that firms would spend more to buy permits or receive more from selling permits, hence representing a "green" policy of encouraging domestic abatement. In contrast, negative t_i corresponds to a "brown" policy that discourages domestic abatement.

Next, we introduce the objective functions of firms and governments. Firm i selects optimal emission level e_i to minimize its cost of complying with $\overline{w}_i$, which is the sum of self-abatement cost and permit trading expense or revenue. If government i regulates using t_i, firm i's compliance cost can be written as

$$FC_i(e_i) \equiv C_i(e_i) + (p + t_i)(e_i - \overline{w}_i), \ i = 1, \ldots, N, \tag{1}$$

where the sign of $(e_i - \overline{w}_i)$, i.e., the status of firm i's buying or selling permits, is endogenously determined; and positive (negative) $(p+t_i)(e_i - \overline{w}_i)$ represents firm i's permit trading expense (revenue). Government i chooses optimal taxing or subsidizing level t_i to minimize her social cost, which equals firm i's compliance cost minus the taxing or subsidizing amount. Since taxes and subsidies are transfer payments between governments and their firms, country i's social cost can be written as

$$SC_i(t_i) \equiv C_i(e_i) + p(e_i - \overline{w}_i), \ i = 1, \ldots, N. \tag{2}$$

On the other hand, if government i decides not to intervene, then firm i has compliance cost $FC_i(e_i) \equiv C_i(e_i) + p(e_i - \overline{w}_i)$, i.e., t_i in (1) vanishes. Based on the settings, various results are derived and compared in the following sections.

3 Optimal Strategic Regulations in Imperfectly Competitive IET

This section analyzes the game of strategic regulations in imperfectly competitive IET. Players include governments of the trading countries, who decide whether to regulate permit trading and optimal regulating degrees if regulation is adopted; and representative firms, who must comply with the national emission caps and determine their corresponding emission levels. Similar to Westskog (1996), we model traders' interactions in imperfectly competitive IET by a leader-follower game, in which price-influencing firms are leaders, and price-taking firms are followers. However, unlike Westskog (1996), we allow governments to intervene in IET.

Our four-stage game of IET proceeds as follows. First, all governments simultaneously and independently decide whether to regulate the trading. Second, governments choosing to regulate determine optimal taxing or subsidizing levels to minimize their respective social costs. And no ensuing decisions are needed for governments resolving no-intervention. Third, given employed policies, price-influencing firms select optimal emission levels to minimize their individual compliance costs, and equilibrium permit prices are settled based on the market-clearing condition. Finally, given equilibrium permit prices and adopted policies, price-taking firms choose optimal emission levels to minimize their individual compliance costs.

To obtain subgame perfect equilibrium (hereafter SPE) by backward induction, we first derive optimal behaviors of governments and firms under all possible regulating situations. There are 2^N cases for N countries, and can be classified into three categories: (i) no-intervention of all countries, (ii) active-intervention of all countries, and (iii) active-intervention of some countries. By comparing the associated social costs under all situations, we can decide optimal regulations in the first stage. The outcomes are presented below.

3.1 Equilibria under All Possible Regulations

This section solves equilibria under all possible regulating situations. We group governments and firms into four categories according to policy type and their having market power or not. Suppose the first $L(1 \leq L < N)$ countries own market power and the remaining $(N - L)$ countries behave as price-takers. Among the L price-influencing countries, let the first $L'(0 \leq L' \leq L)$ governments regulate. Index firms and governments in these L' countries by r, $r = 1, \ldots, L'$; and those in the remaining $(L - L')$ countries by s, $s = (L'+1), \ldots, L$. For the $(N - L)$ price-taking countries, assume that there are $(N' - L)$, $L \leq N' \leq N$, regulating governments. Index firms and governments in the $(N' - L)$ countries by u, $u = (L+1), \ldots, N'$; and those in the remaining $(N - N')$ countries by v, $v = (N' + 1), \ldots, N$. All governments regulate if $L' = L$ and $N' = N$, and no government regulates if $L' = 0$ and $N' = L$. Players' indices are summarized in Table 1.

Table 1: Indexes of Players

	Regulating	No regulating
With Market Power	• L' countries • Players are indexed by $r = 1, \ldots, L'$	• $(L - L')$ countries • Players are indexed by $s = (L' + 1), \ldots, L$
Without Market Power	• $(N' - L)$ countries • Players are indexed by $u = (L + 1), \ldots, N'$	• $(N - N')$ countries • Players are indexed by $v = (N' + 1), \ldots, N$

We start with deriving optimal behaviors of price-taking firms in the last stage of the game. Given permit price p and regulating government u's tax (or subsidy) t_u, price-taking firm u chooses e_u^* to minimize its compliance cost

$$\min_{e_u \geq 0} \quad FC_u(e_u) = C_u(e_u) + (p + t_u)(e_u - \overline{w}_u), \; u = (L + 1), \ldots, N'. \tag{3}$$

The first-order conditions for interior solutions are

$$-C_u'(e_u^*) = p + t_u, \; u = (L + 1), \ldots, N'. \tag{4}$$

On the other hand, price-taking firm v in no-regulating countries has an objective function similar to (3) except that t_v vanishes. The associated first-order conditions for interior solutions are

$$-C_v'(e_v^*) = p, \; v = (N' + 1), \ldots, N. \tag{5}$$

The second-order conditions for these problems hold since $C_n''(e_n) > 0$ for all $e_n \geq 0$, $n = u$ or v. Equations (4) and (5) suggest that price-taking firms adjust their respective emissions until the marginal cost and the marginal saving of abatement are equal. The equations implicitly define price-taking firms' downward-sloping demand functions for permits, i.e., $\frac{\partial e_n^*}{\partial p} = \frac{-1}{C_n''(e_n^*)} < 0$ for $n = u$ or v.

Next, we solve the third stage of the game regarding price-influencing firms. Given price-taking firms' optimal emissions $\{e_n^*\}_{n=L+1}^{N}$ and regulating government r's tax (or subsidy) t_r, price-influencing firm r chooses e_r^* to minimize its compliance cost subject to the market-clearing condition.

$$\min_{e_r \geq 0} \quad FC_r(e_r) = C_r(e_r) + (p + t_r)(e_r - \overline{w}_r),\ r = 1, \ldots, L', \tag{6}$$

$$\text{s.t.} \quad \sum_{r=1}^{L'} e_r + \sum_{s=L'+1}^{L} e_s + \sum_{u=L+1}^{N'} e_u^*(p, t_u) + \sum_{v=N'+1}^{N} e_v^*(p) = \sum_{i=1}^{N} \overline{w}_i. \tag{7}$$

According to (7), permit price p can be expressed as a function of $\{e_m\}_{m=1}^{L}$ with

$$\frac{\partial p}{\partial e_m} = \frac{-1}{\sum\limits_{n=L+1}^{N} (\partial e_n^* / \partial p)} > 0, \text{ for } m = r \text{ or } \ s. \tag{8}$$

Equation (8) suggests that permit prices and price-influencing firms' emissions are positively correlated. If price-influencing firms discharge more, then permits available to price-taking firms fall and permit prices rise.

Substituting $p = p(\{e_m\}_{m=1}^{L})$ from (8) into objective function (6) and deriving the first-order conditions for interior solutions e_r^* yield

$$-C_r'(e_r^*) = p + t_r + \left(\frac{\partial p}{\partial e_r}\right)\left(e_r^* - \overline{w}_r\right),\ r = 1, \ldots, L'. \tag{9}$$

Price-influencing firm s in no-regulating countries has an objective function similar to (6) except that t_s vanishes. The associated first-order conditions for interior solutions are

$$-C_s'(e_s^*) = p + \left(\frac{\partial p}{\partial e_s}\right)\left(e_s^* - \overline{w}_s\right),\ s = (L' + 1), \ldots, L. \tag{10}$$

The second-order conditions for these problems hold since $C_m''(e_m) + 2(\frac{\partial p}{\partial e_m}) > 0$ for all $e_m \geq 0$, $m = r$ or s. Equations (9) and (10) indicate that price-influencing firms adjust their respective emissions until the marginal cost of abatement equals the marginal saving of abatement, which is composed of permit price p, tax (or subsidy) of permit trading t_r in regulating countries, and marginal price effect due to market power $\left(\frac{\partial p}{\partial e_m}\right)\left(e_m^* - \overline{w}_m\right)$. For a permit buyer, the marginal price effect is positive, meaning that one more unit of abatement (or decrease in emissions) would save trading expenditure by $\left(\frac{\partial p}{\partial e_m}\right)\left(e_m^* - \overline{w}_m\right)$. Oppositely, for a permit seller, this marginal price effect is negative, reflecting that an additional unit of abatement would reduce trading revenue by $\left(\frac{\partial p}{\partial e_m}\right)\left(e_m^* - \overline{w}_m\right)$.

The market-clearing condition in (7) implies that permit price p is affected by price-taking governments' regulation levels, i.e., $\{t_u\}_{u=L+1}^{N'}$. Accordingly, equations (9)-(10) imply that price-influencing firms' optimal emissions $\{e_m^*\}_{m=1}^{L}$ are affected by all regulating governments' taxes or subsidies, i.e., $\{t_r\}_{r=1}^{L'}$ and $\{t_u\}_{u=L+1}^{N'}$. Given $e_m^* = e_m^*(\{t_r\}_{r=1}^{L'}, \{t_u\}_{u=L+1}^{N'})$, $m = 1, \ldots, L$, equations (4), (5) and (7) suggest that price-taking firms' optimal emissions and equilibrium permit prices are affected by $\{t_r\}_{r=1}^{L'}$ and $\{t_u\}_{u=L+1}^{N'}$ as well. Particularly, the impacts of regulating governments' taxes or subsidies on their own firms' optimal emissions and equilibrium permit prices can be described below.

$$\frac{\partial e_r^*}{\partial t_r} < 0 \ \text{ and } \ \frac{\partial p^*}{\partial t_r} < 0, \ r = 1, \ldots, L', \tag{11}$$

$$-1 < \frac{\partial p^*}{\partial t_u} < 0 \ \text{ and } \ \frac{\partial e_u^*}{\partial t_u} < 0, \ u = (L+1), \ldots, N'. \tag{12}$$

Proofs of (11)-(12) are in the Appendix. If regulating governments adopt a greener policy (i.e., higher t_r or t_u), their firms' marginal savings of abatement increase. Thus, firms abating more would have lower excess demands for permits. Consequently, equilibrium permit prices fall.

Finally, we work out optimal regulating levels for intervening governments in the second stage of the game. Given all firms' optimal emissions $\{e_i^*\}_{i=1}^{N}$ and equilibrium permit price p^*, price-taking government u chooses t_u^* to minimize her social cost:

$$\min_{t_u \in R} \quad SC_u(t_u) = C_u(e_u^*) + p^*(e_u^* - \overline{w}_u), \quad u = (L+1), ..., N'. \tag{13}$$

The first-order conditions for interior solutions are

$$\left(C_u'(e_u^*) + p^*\right)\left(\frac{\partial e_u^*}{\partial t_u}\right) + \left(\frac{\partial p^*}{\partial t_u}\right)\left(e_u^* - \overline{w}_u\right) = 0, \quad u = (L+1), \ldots, N'. \tag{14}$$

Suppose the associated second-order conditions hold. Using (4), equation (14) can be rewritten as

$$t_u^* = \Gamma_u(e_u^* - \overline{w}_u), \quad u = (L+1), \dots, N', \tag{15}$$

where

$$\Gamma_u = \frac{(\partial p^*/\partial t_u)}{(\partial e_u^*/\partial t_u)} > 0 \;\; \text{by}(12). \tag{16}$$

Equations (15) and (16) together imply that

$$t_u^* \gtreqless 0 \;\; \text{iff} \;\; e_u^* \gtreqless \overline{w}_u, \quad u = (L+1), \dots, N'. \tag{17}$$

This means that price-taking governments who regulate will tax emission trading unless their firms' emissions equal to the required caps. The intuition is given below. Since firms' marginal abatement costs equal permit prices by (4) when $t_u = 0$, governments' policies should be able to alter permit prices toward desired directions of their firms. Thus, to lower the price, a permit-buying country should tax IET to reduce its firm's excess demand for permits. In contrast, to raise the price, a permit-selling country should tax IET to decrease its firm's excess supply of permits.

Price-influencing governments have the same objective functions and first-order conditions as (13) and (14), respectively. Using (9), the associated first-order conditions can be rearranged as

$$t_r^* = \Pi_r(e_r^* - \overline{w}_r), \quad r = 1, \dots, L', \tag{18}$$

where

$$\Pi_r = \Big[\Big(\frac{\partial p^*}{\partial t_r}\Big) - \Big(\frac{\partial p}{\partial e_r}\Big)\Big(\frac{\partial e_r^*}{\partial t_r}\Big)\Big]\Big(\frac{\partial e_r^*}{\partial t_r}\Big)^{-1} \begin{cases} = 0 & if \quad L = 1 \\ < 0 & if \quad L \geq 2 \end{cases} \tag{19}$$

Proof of (19) is in the Appendix. Price-influencing governments will not intervene in IET when their firms' emissions equal the required caps. The same outcome would occur if there is only one price-influencing country in the market. Because this country has solitary power to affect equilibrium permit prices, no regulation is needed. By contrast, if two or more countries have market power, then equations (18)-(19) suggest that

$$t_r^* \gtreqless 0 \;\; \text{iff} \;\; e_r^* \lesseqgtr \overline{w}_r, \quad r = 1, \dots. L'. \tag{20}$$

Equation (20) states that regulating governments will subsidize permit trading. Since price-influencing buyers have marginal abatement costs greater than permit prices by (9) when $t_r = 0$, increasing permit purchases is beneficial. Hence, governments should encourage firms' trading in IET through subsidies. This policy will induce a desired quantity effect of more permit purchases, i.e., $-\left(\frac{\partial p}{\partial e_r}\right)\left(\frac{\partial e_r^*}{\partial t_r}\right) > 0$ by (8) and (11), which would lower firms' emission abatements and abatement costs. However, the policy would also cause an undesired price effect of higher purchasing expenses because equilibrium permit prices rise from larger demands, i.e., $\frac{\partial p^*}{\partial t_r} < 0$ by (11). Nevertheless, we have $\left(\frac{\partial p^*}{\partial t_r}\right) - \left(\frac{\partial p}{\partial e_r}\right)\left(\frac{\partial e_r^*}{\partial t_r}\right) > 0$ due to $\prod_r < 0$ by (19) and $\frac{\partial e_r^*}{\partial t_r} < 0$ by (11). It means that the desired quantity effect dominates. Hence, it is optimal for permit-buying countries with market power to adopt subsidizing policies.

Similarly, we can display that subsidizing policies are also the best choices for permit-selling countries with market power. When no government regulates IET, price-influencing sellers have marginal abatement costs smaller than permit prices by (9). Expanding permit sales is thus beneficial. Although subsidizing policies of permit-selling countries would cause an undesired price effect of decreasing selling revenues, they have a desired effect of selling more permits. Because the quantity effect dominates, it is optimal for permit-selling countries with market power to employ subsidizing policies.

These results are summarized in Theorem 1.

Theorem 1. *If governments decide to regulate IET under imperfect competition, price-taking countries should tax their firms' trading. For countries with market power, however, optimal policies would depend on the number of these countries. When there is only one country with market power, no-intervention is optimal. In contrast, if countries with market power are more than one, these countries should subsidize their firms' permit trading.*

3.2 Active-Intervention Or No-Intervention

Based on the equilibria derived in Section 3.1, we can obtain individual countries' social costs in all regulating conditions by substituting associated equilibria into the social cost function defined in (2). Through comparing social costs in the 2^N cases, we can uncover individual governments' optimal choices between active- and no-intervention. However, without specific function forms of firms' abatement costs, it is hard to obtain definite theoretical conclusions about intervention or not because the interplay of endogenous variables $\{e_i\}_{i=1}^N$ and

p is quite complex. To provide more real-world insights concerning governments' strategic regulations, a numerical application to the Annex-1 emissions trading is given in the next section.

4 A Numerical Application to the Annex-1 Emissions Trading

Since the Copenhagen meeting does not reach a concrete agreement on emission reduction, this section applies our game-theoretical model to the Annex-1 emissions trading under the Kyoto Protocol. Based on the numerical findings on social costs, we can infer whether governments would regulate at SPE. The impacts of regulations on efficiency of IET will be analyzed as well.

Suppose we have a quadratic abatement cost function

$$C_i(e_i) = \frac{\alpha_i}{2}(\bar{b}_i - e_i)^2, \quad i = 1, ..., N, \tag{21}$$

where $\alpha_i > 0$ is a technological parameter, which increases with falling abatement efficiency; $\bar{b}_i$ is the unconstrained baseline emission level for the representative firm in country i; and $(\bar{b}_i - e_i)$ is firm i's abatement level.

Because the Kyoto Protocol enters into force without the US, the numerical application here simulates IET among three significant Annex-1 countries. They are Russia (country 1), the European Union (country 2), and Japan (country 3). Table 2 summarizes the data used in our simulations. Emission levels $\bar{b}_i$ and emission caps $\overline{w}_i$, $i = 1, 2, 3$, originating from the OECD GREEN model (OECD, 1999), are taken from the GTAP-E model (Burniaux and Truong, 2002). The emission caps are required relative to corresponding emission levels of the Annex-1 countries in a baseline scenario. Except Russia, we have $\bar{b}_i > \overline{w}_i$, $i = 2, 3$. Thus, $(\bar{b}_i - \overline{w}_i)$ represents abatement levels required by the Kyoto Protocol for the European Union and Japan. Since $\bar{b}_1 < \overline{w}_1$, $(\overline{w}_1 - \bar{b}_1)$ is the amount of hot air that could be sold in the IET market. The hot air is mainly caused by the economic disarray following collapse of the Soviet Union. Values of parameter α_i, $i = 1, 2, 3$, are estimated based on the GTAP-E model.

Table 2: **Data Used in the Numerical Analysis**

Countries/Regions	$\bar{b}_i$(MtC)[a]	$\overline{w}_i$(MtC)[a]	α_i
Russia	372.53	420.47	0.97
The EU	911.16	707.06	0.64
Japan	337.22	229.98	1.58

Source: $\bar{b}_i$ and $\overline{w}_i$ are take from the GTAP-E model, and α_i are estimated by the same model.

a. MtC: million tons of carbon.

As in the literature on imperfectly competitive IET (e.g., Bohringer et al., 2007), we attribute Russian market power in IET to the hot air. Moreover, either the European Union or Japan, or both are assumed to be price takers.Thus we conduct simulations of groups A, B, and C; with {Russia}, {Russia, the EU} , and {Russia, Japan} having market power, respectively. In each group, we have 2^3 scenarios. These scenarios and their associated equilibrium permit prices are summarized in Table 3. The three Annex-1 countries' optimal emissions, permit-trading amounts, regulating levels under active-intervention, as well as social costs in groups A, B, and C are presented in Tables 4, 5, and 6, respectively.

Optimal emissions and permit-trading amounts are measured by million tons of carbon (MtC). Positive (negative) values in rows of "permit purchases" indicate the permit-buying (permit-selling) status of a country. Optimal regulations t_i are measured by US dollars per ton of carbon (US$/tC). As mentioned in Section 2, if firm i is a permit buyer, t_i>(<)0 means its government taxing (subsidizing) the purchases. In contrast, if firm i is a permit seller, t_i>(<)0 signifies its government subsidizing (taxing) the sales. Finally, social costs are appraised by millions of US$.

As manifested in Tables 4-6, if active-intervention is chosen, price-taking countries would tax firms' permit trading. As there is only one country with market power (i.e., Russia in group A), zero-subsidy is optimal for this country. In contrast, if countries with market power are more than one, these countries would subsidize firms' permit trading (i.e., Russia and the EU in group B, Russia and Japan in group C). The results are consistent with Theorem 1 and equations (18)-(20). Differences of equilibrium permit prices among scenarios in each group could be explained by regulating levels. For instance, in group A, scenarios A2 and A8 have the highest tax, hence their equilibrium permit price (\$75.79 in Table 3) is the lowest. Since regulating levels together with equilibrium permit prices would affect firms' marginal savings of abatement, relative magnitudes of firms' optimal emissions among scenarios in each group are uncertain, so are countries' equilibrium social costs. Our observations are outlined below.

First, zero-subsidy is optimal for price-influencing Russia in group A, thus results for Russia's adopting active-intervention or no-intervention are the same (A1 and A3; A2 and A8; A4 and A6; A5 and A7). Second, as only one country regulates (A4-A5, B3-B5, C3-C5), her equilibrium social cost will be lower than that under no-government's regulation (A1, B1, C1). Third, when two or three countries regulate, equilibrium social costs of all countries could be higher or lower than the corresponding under no-government's regulation. Take Scenario B7 (Russia and Japan regulate) as an example. Russia's social benefit ($|-\text{US}\$4,335.26|$ millions) is smaller than its number in Scenario B1 ($|-\text{US}\$5,719.46|$ millions), while the EU's equilibrium social cost (US\$11,972.08 millions) is smaller than its number in Scenario B1 (US\$12,973.19 millions).

Fourth, governments' regulations would change the total efficiency of IET, measured by the sum of all countries' equilibrium social costs. The total efficiency is higher if the sum is lower. Given distortions from imperfectly competitive market structure, subsidizing policies of price-influencing countries would promote permit trading and mitigate efficiency loss. In contrast, taxing policies of price-taking countries would impede permit trading and cause efficiency loss. Accordingly, scenarios with the highest total trading efficiency in each group are those with price-influencing countries regulating but price-taking countries not regulating (A3, B6, C6). Oppositely, scenarios with the lowest total trading efficiency in each group are those with price-taking countries regulating but price-influencing countries not regulating (A8, B5, C5). These outcomes are summarized in Observation 1.

Observation 1. *Strategically regulating imperfectly competitive IET may lead to higher or lower social costs for individual countries, as compared to their no-intervention situations. Nevertheless, scenarios with the highest (lowest) total trading efficiency always have price-influencing countries subsidizing (not regulating) but price-taking countries not regulating (taxing).*

Table 3: Simulation Scenarios and Equilibrium Permit Prices

A. Countries with Market Power: Russia		
	Regulating Countries	Permit Price(US$/tC)
A1	None	96.21
A2	Russia, the EU and Japan	75.79
A3	Russia	96.21
A4	The EU	82.09
A5	Japan	92.54
A6	Russia and the EU	82.09
A7	Russia and Japan	92.54
A8	The EU and Japan	75.79
B. Countries with Market Power: Russia and the EU		
	Regulating Countries	Permit Price (US$/tC)
B1	None	100.19
B2	Russia, the EU and Japan	77.90
B3	Russia	87.81
B4	The EU	103.31
B5	Japan	84.58
B6	Russia and the EU	91.86
B7	Russia and Japan	71.27
B8	The EU and Japan	90.24
C. Countries with Market Power: Russia and Japan		
	Regulating Countries	Permit Price (US$/tC)
C1	None	95.49
C2	Russia, the EU and Japan	74.37
C3	Russia	92.30
C4	Japan	96.61
C5	The EU	76.42
C6	Russia and Japan	93.43
C7	Russia and the EU	72.20
C8	Japan and the EU	78.56

Table 4: Equilibria and Social Costs in Scenarios A1-A8

	Russia	The EU	Japan	Sum
Scenario A1 Regulating Countries: None				
Optimal Emissions (MtC)	320.36	760.83	276.33	
Permit Purchases (MtC)	-100.11	53.77	46.34	
Optimal Regulations(US$/tC)	n.a.	n.a.	n.a.	
Social Costs(millions of US dollars)	-8,311.84	12,404.93	7,387.96	11,481.04
Scenario A2 Regulating Countries: Russia, the EU and Japan				
Optimal Emissions (MtC)	334.68	746.53	276.30	
Permit Purchases (MtC)	-85.79	39.47	46.32	
Optimal Regulations(US$/tC)	0.00	29.58	20.46	
Social Costs(millions of US dollars)	-5,806.96	11,664.36	6,441.98	12,299.38
Scenario A3 Regulating Countries: Russia				
Optimal Emissions (MtC)	320.36	760.83	276.33	
Permit Purchases (MtC)	-100.11	53.77	46.34	
Optimal Regulations(US$/tC)	0.00	n.a.	n.a.	
Social Costs(millions of US dollars)	-8,311.84	12,404.93	7,387.96	11,481.04
Scenario A4 Regulating Countries: the EU				
Optimal Emissions (MtC)	330.26	741.99	285.26	
Permit Purchases (MtC)	-90.21	34.93	55.28	
Optimal Regulations(US$/tC)	n.a.	26.18	n.a.	
Social Costs(millions of US dollars)	-6,538.94	12,025.33	6,670.56	12,156.96

Table 4: Equilibria and Social Costs in Scenarios A1-A8 (cont.)

	Russia	The EU	Japan	Sum
Scenario A5 Regulating Countries: Japan				
Optimal Emissions (MtC)	322.93	766.57	268.02	
Permit Purchases (MtC)	-97.54	59.51	38.03	
Optimal Regulations(US$/tC)	n.a.	n.a.	16.80	
Social Costs(millions of US dollars)	-7,833.21	12,197.05	7,302.91	11,666.74
Scenario A6 Regulating Countries: Russia and the EU				
Optimal Emissions (MtC)	330.26	741.99	285.26	
Permit Purchases (MtC)	-90.21	34.93	55.28	
Optimal Regulations(US$/tC)	0.00	26.18	n.a.	
Social Costs(millions of US dollars)	-6,538.94	12,025.33	6,670.56	12,156.96
Scenario A7 Regulating Countries: Russia and Japan				
Optimal Emissions (MtC)	322.93	766.57	268.02	
Permit Purchases (MtC)	-97.54	59.51	38.03	
Optimal Regulations(US$/tC)	0.00	n.a.	16.80	
Social Costs(millions of US dollars)	-7,833.21	12,197.05	7,302.91	11,666.74
Scenario A8 Regulating Countries: the EU and Japan				
Optimal Emissions (MtC)	334.68	746.53	276.30	
Permit Purchases (MtC)	-85.79	39.47	46.32	
Optimal Regulations(US$/tC)	n.a.	29.58	20.46	
Social Costs(millions of US dollars)	-5,806.96	11,664.36	6,441.98	12,299.38

Table 5: Equilibria and Social Costs in Scenarios B1-B8

	Russia	The EU	Japan	Sum
Scenario B1 Regulating Countries: None				
Optimal Emissions (MtC)	362.94	720.77	273.81	
Permit Purchases (MtC)	-57.53	13.71	43.82	
Optimal Regulations(US$/tC)	n.a.	n.a.	n.a.	
Social Costs(millions of US dollars)	-5,719.46	12,973.19	7,567.58	14,821.32
Scenario B2 Regulating Countries: Russia, the EU and Japan				
Optimal Emissions (MtC)	354.75	739.69	263.07	
Permit Purchases (MtC)	-65.72	32.63	33.08	
Optimal Regulations(US$/tC)	43.17	-19.73	39.26	
Social Costs(millions of US dollars)	-4,966.17	11,950.41	6,921.20	13,905.44
Scenario B3 Regulating Countries: Russia				
Optimal Emissions (MtC)	349.52	726.35	281.65	
Permit Purchases (MtC)	-70.95	19.29	51.66	
Optimal Regulations(US$/tC)	46.61	n.a.	n.a.	
Social Costs(millions of US dollars)	-5,973.06	12,623.39	6,976.18	13,626.51
Scenario B4 Regulating Countries: the EU				
Optimal Emissions (MtC)	361.72	723.96	271.83	
Permit Purchases (MtC)	-58.75	16.90	41.85	
Optimal Regulations(US$/tC)	n.a.	-10.22	n.a.	
Social Costs(millions of US dollars)	-6,013.19	12,959.95	7,701.20	14,647.95

Table 5: Equilibria and Social Costs in Scenarios B1-B8 (cont.)

	Russia	The EU	Japan	Sum
Scenario B5 Regulating Countries: Japan				
Optimal Emissions (MtC)	369.06	727.80	260.65	
Permit Purchases (MtC)	-51.41	20.74	30.67	
Optimal Regulations(US$/tC)	n.a.	n.a.	36.40	
Social Costs(millions of US dollars)	-4,342.28	12,512.95	7,225.52	15,396.20
Scenario B6 Regulating Countries: Russia and the EU				
Optimal Emissions (MtC)	347.38	731.05	279.08	
Permit Purchases (MtC)	-73.09	23.99	49.10	
Optimal Regulations(US$/tC)	48.02	-14.50	n.a.	
Social Costs(millions of US dollars)	-6,407.36	12,584.31	7,180.40	13,357.35
Scenario B7 Regulating Countries: Russia and Japan				
Optimal Emissions (MtC)	358.26	733.80	265.46	
Permit Purchases (MtC)	-62.21	26.74	35.48	
Optimal Regulations(US$/tC)	40.87	n.a.	42.11	
Social Costs(millions of US dollars)	-4,335.26	11,972.08	6,596.42	14,233.23
Scenario B8 Regulating Countries: the EU and Japan				
Optimal Emissions (MtC)	366.85	732.06	258.61	
Permit Purchases (MtC)	-53.62	25.00	28.62	
Optimal Regulations(US$/tC)	n.a	-15.11	33.97	
Social Costs(millions of US dollars)	-4,823.10	12,520.49	7,465.01	15,162.39

Table 6: Equilibria and Social Costs in Scenarios C1-C8

	Russia	The EU	Japan	Sum
Scenario C1 Regulating Countries: None				
Optimal Emissions (MtC)	332.27	761.95	263.29	
Permit Purchases (MtC)	-88.20	54.89	33.31	
Optimal Regulations(US$/tC)	n.a.	n.a.	n.a.	
Social Costs(millions of US dollars)	-7,636.28	12,366.00	7,498.38	12,228.10
Scenario C2 Regulating Countries: Russia, Japan and the EU				
Optimal Emissions (MtC)	338.07	742.82	276.63	
Permit Purchases (MtC)	-82.41	35.76	46.65	
Optimal Regulations(US$/tC)	11.80	33.37	-8.49	
Social Costs(millions of US dollars)	-5,552.27	11,727.72	6,369.16	12,544.62
Scenario C3 Regulating Countries: Russia				
Optimal Emissions (MtC)	325.84	766.94	264.73	
Permit Purchases (MtC)	-94.63	59.88	34.75	
Optimal Regulations(US$/tC)	13.55	n.a.	n.a.	
Social Costs(millions of US dollars)	-7,676.90	12,182.61	7,358.29	11,864.00
Scenario C4 Regulating Countries: Japan				
Optimal Emissions (MtC)	331.58	760.21	265.72	
Permit Purchases (MtC)	-88.89	53.15	35.74	
Optimal Regulations(US$/tC)	n.a.	n.a.	-6.51	
Social Costs(millions of US dollars)	-7,773.93	12,426.10	7,491.01	12,143.18

Table 6: Equilibria and Social Costs in Scenarios C1-C8 (cont.)

	Russia	The EU	Japan	Sum
Scenario C5 Regulating Countries: the EU				
Optimal Emissions (MtC)	344.12	741.51	271.88	
Permit Purchases (MtC)	-76.35	34.45	41.90	
Optimal Regulations(US$/tC)	n.a.	32.15	n.a.	
Social Costs(millions of US dollars)	-5,443.36	11,842.55	6,574.48	12,973.67
Scenario C6 Regulating Countries: Russia and Japan				
Optimal Emissions (MtC)	325.07	765.17	267.28	
Permit Purchases (MtC)	-95.40	58.11	37.29	
Optimal Regulations(US$/tC)	13.66	n.a.	-6.79	
Social Costs(millions of US dollars)	-7,821.25	12,249.56	7,349.10	11,777.41
Scenario C7 Regulating Countries: Russia and the EU				
Optimal Emissions (MtC)	339.54	744.19	273.78	
Permit Purchases (MtC)	-80.93	37.13	43.80	
Optimal Regulations(US$/tC)	11.59	34.65	n.a.	
Social Costs(millions of US dollars)	-5,315.71	11,602.08	6,341.71	12,628.08
Scenario C8 Regulating Countries: Japan and the EU				
Optimal Emissions (MtC)	342.79	740.15	274.57	
Permit Purchases (MtC)	-77.68	33.09	44.59	
Optimal Regulations(US$/tC)	n.a.	30.88	-8.12	
Social Costs(millions of US dollars)	-5,673.88	11,957.79	6,603.53	12,887.44

Finally, we examine governments' choices between active-intervention and no-intervention in the first stage of the game. In group A, we have two SPEs where price-influencing Russia chooses active- or no-intervention while price-taking Japan and the EU adopt active-intervention.One SPE in group B has all countries regulating; while the other SPE has price-influencing Russia and the EU not regulating, but price-taking Japan regulating. The only one SPE in group C has price-influencing Russia and Japan not regulating, but the price-taking EU intervening. Derivations of these SPEs are available upon request.

Several important implications can be summarized as follows. First, all countries deciding no-intervention in the first stage cannot be supported by any SPE. This finding is different from Hwang and Schulman's (1993), in which the no-intervention equilibrium could occur. Second, all or some countries will regulate at SPE. Neglecting intervention choices may lead to biased outcomes, thus governments' strategic regulations should be considered while studying IET. Third, SPE may occur in scenarios with the lowest total trading efficiency (e.g., C5), but not in scenarios with the highest total trading efficiency (e.g., C6). That is because governments' regulation decisions depend on self-interests, instead of global interests. Fourth, for the two SPEs in group B, the all countries regulating equilibrium Pareto dominates the other one since countries' social costs are lower. Finally, results in group C show that no-intervention of price-influencing countries could happen. This is distinct from Brander and Spencer's (1985), which states that subsidizing international oligopoly industries is exporting (also price-influencing) country's best policy under imperfect competition. When the price-taking EU does not regulate (scenarios C1, C3, C4 and C6), price-influencing Russia and Japan will subsidize permit trading at equilibrium. In contrast, as the price-taking EU decides to intervene in permit trading, price-influencing Russia and Japan will not. With price-taking countries not regulating, price-influencing governments can fulfill the cost-shifting effect by enlarging trading amounts through subsidies. Oppositely, if price-taking governments impose tax to hamper firms' permit trading, price-influencing countries would choose no-intervention to avoid the adverse effect caused by price-taking countries' taxing. This outcome highlights the necessity of considering no-intervention as a policy choice, and shows that a country's decisions about strategically regulating IET may be affected by other countries' intervention resolutions.

These findings are summarized in Observation 2.

Observation 2. *When countries play non-cooperatively in deciding whether to regulate IET, SPE could occur in scenarios with the lowest total trading efficiency, but not in scenarios with the highest total trading efficiency. No-intervention of all countries cannot be part of any SPE. Instead, all or some countries will regulate at SPE. In the latter case, price-influencing countries do not intervene and price-taking countries would adopt active-intervention.*

5 Conclusion

This paper investigates governments' optimal strategic regulations in an imperfectly competitive IET market. We expand relevant literature by applying strategic trade polices to IET and considering no-intervention a choice. The results show that it is optimal for price-taking countries to tax permit trading if they decide to regulate. For price-influencing countries, optimal policies depend on the size of this country group. When there is only one country with market power, she will not regulate. In contrast, if countries with market power are more than one, they would subsidize firms' permit trading. Our major numerical findings in simulating the Annex-1 emissions trading are as follows. First, strategic regulations in IET may lead to higher or lower social costs than those under no-intervention for individual countries. The total trading efficiency is always the highest as price-influencing countries regulate but price-taking countries do not. Second, no-intervention of all countries cannot be part of any SPE. By contrast, all or some countries regulate at SPE, which justifies the necessity of considering governments' strategic regulations. Third, SPE may occur in scenarios with the lowest total trading efficiency, but not in scenarios with the highest total trading efficiency.

This paper presumes an agreed permit allocation, which can be relaxed in the future. In other words, we can endogenize allowance choices and analyze countries' trading incentives and the environmental effectiveness of IET. On the other hand, since strategic regulations may affect countries' costs of complying with given abatement targets, they would in turn influence commodity prices and trade competitiveness. When the spillover effect of IET regulations on commodity markets are taken into account, some of our outcomes, such as optimal strategic regulations in IET, may change accordingly.

Appendix

Proof of (11):

Denote H the Hessian matrix of L equations in (9) and (10) with

$$H = \begin{bmatrix} C_1''(e_1^*) + 2A & A & \dots & A \\ A & C_2''(e_2^*) + 2A & \dots & A \\ \vdots & \vdots & \dots & \vdots \\ A & A & \dots & C_L''(e_L^*) + 2A \end{bmatrix} = A \begin{bmatrix} K_1 & 1 & \dots & 1 \\ 1 & K_2 & \dots & 1 \\ \vdots & \vdots & \dots & \vdots \\ 1 & 1 & \dots & K_L \end{bmatrix},$$

where $A = \frac{\partial p}{\partial e_m} = \frac{-1}{\sum\limits_{n=L+1}^{N} (\partial e_n^* / \partial p)} > 0$ and $K_m = \frac{C_m''(e_m^*)+2A}{A}$ with $K_m > 2$, given $C_m''(e_m^*) > 0$, $m = 1, \dots, L$.

Letting $\hat{H} = \begin{bmatrix} K_1 & 1 & \dots & 1 \\ 1 & K_2 & \dots & 1 \\ \vdots & \vdots & \dots & \vdots \\ 1 & 1 & \dots & K_L \end{bmatrix}$, we can show $|\hat{H}| = \Big[\prod\limits_{m=1}^{L} (K_m - 1) \Big] \Big[1 + \sum\limits_{m=1}^{L} \frac{1}{K_m - 1} \Big] > 1$ by $K_m > 2$. Applying Cramer's rule, we acquire

$$\frac{\partial e_r^*}{\partial t_r} = \frac{-1}{A|\hat{H}|} C_{rr} < 0,$$

where $C_{rr} = (-1)^{r+r} \Big[\prod\limits_{m \neq r}^{L} (K_m - 1) \Big] \Big[1 + \sum\limits_{m \neq r}^{L} \frac{1}{K_m - 1} \Big] > 0$ is the $(r, r)^{th}$ cofactor of $\hat{H}$.

On the other hand, the market-clearing condition for the IET system at equilibrium is

$$\sum_{m=1}^{L} e_m^*(t_1, .., t_{L'}; t_{L+1}, .., t_{N'}) + \sum_{u=L+1}^{N'} e_u^*(p^*(t^1, .., , t_{L'}; t_{L+1}, .., t_{N'}), t_u)$$
$$+ \sum_{v=N'+1}^{N} e_v^*(p^*(t_1, .., t_{L'}; t_{L+1}, .., t_{N'})) = \sum_{i=1}^{N} \overline{w_i}.$$

Differentiating this equation with respect to t_r yields

$$\sum_{m=1}^{L} \frac{\partial e_m^*}{\partial t_r} + \sum_{n=L+1}^{N} \frac{\partial e_n^*}{\partial p} \cdot \frac{\partial p^*}{\partial t_r} = 0.$$

Rearranging the above equation gives $\frac{\partial p^*}{\partial t_r} = -\Big(\sum_{n=L+1}^{N} \frac{\partial e_n^*}{\partial p}\Big)^{-1}\Big(\sum_{m=1}^{L} \frac{\partial e_m^*}{\partial t_r}\Big)$. Substituting (8), i.e., $\frac{\partial p}{\partial e_r} = \frac{-1}{\sum_{n=L+1}^{N}\left(\partial e_n^*/\partial p\right)} > 0$, into this equation produces

$$\frac{\partial p^*}{\partial t_r} = \Big(\frac{\partial p}{\partial e_r}\Big)\Big(\sum_{m=1}^{L} \frac{\partial e_m^*}{\partial t_r}\Big) < 0 \quad \text{since} \quad \Big(\sum_{m=1}^{L} \frac{\partial e_m^*}{\partial t_r}\Big) = \frac{-1}{A|\hat{H}|}\Big[\prod_{m \neq r}^{L} (K_m - 1)\Big] < 0.$$

Proof of (12):

Differentiating the market-clearing condition with respect to t_u and rearranging it yields

$$\frac{\partial p^*}{\partial t_u} = A\Big(\frac{\partial e_u^*}{\partial p} + \sum_{m=1}^{L} \frac{\partial e_m^*}{\partial t_u}\Big) = A\Big(\frac{\partial e_u^*}{\partial p}\Big)\Big(1 + \sum_{m=1}^{L} \frac{1}{K_m - 1}\Big)^{-1}.$$

Since $-1 < A\Big(\frac{\partial e_u^*}{\partial p}\Big) < 0$, we have $-1 < \frac{\partial p^*}{\partial t_u} < 0$. Differentiating (4) with respect to t_u gives

$$\frac{\partial e_u^*}{\partial t_u} = \Big(\frac{\partial e_u^*}{\partial p}\Big)\Big(1 + \frac{\partial p^*}{\partial t_u}\Big) < 0.$$

Proof of (19):

Following the proof of (11), we have $\frac{\partial p^*}{\partial t_r} = \Big(\frac{\partial p}{\partial e_r}\Big)\Big(\sum_{m=1}^{L} \frac{\partial e_m^*}{\partial t_r}\Big)$. Thus,

$$\frac{\partial p^*}{\partial t_r} - \Big(\frac{\partial p}{\partial e_r}\Big)\Big(\frac{\partial e_r^*}{\partial t_r}\Big) = \Big(\frac{\partial p}{\partial e_r}\Big)\Big(\sum_{m \neq r}^{L} \frac{\partial e_m^*}{\partial t_r}\Big) \begin{cases} = 0 & if \quad L = 1 \\ > 0 & if \quad L \geq 2, \end{cases}$$

due to $\Big(\frac{\partial p}{\partial e_r}\Big) > 0$ and $\frac{\partial e_m^*}{\partial t_r} = \frac{-1}{A|\hat{H}|} C_{rm} > 0$ for $m = 1, \ldots, L$, $r = 1, \ldots, L'$, and $m \neq r$, where $C_{rm} = (-1)^{2(r+m)-3}\Big[\prod_{t \neq m,r}^{L} (K_t - 1)\Big] < 0$ is the $(r, m)^{th}$ cofactor of $\hat{H}$. Combining these results with (11), we find (19) obvious.

References

Bohringer, C., U. Moslender and B. Sturm (2007) Hot Air for Sale: A Quantitative Assessment of Russia's Near-Term Climate Policy Options, *Environmental and Resource Economics* 38, 545-572.

Bohringer, C. and A. Loschel (2003) Market Power and Hot Air in International Emissions Trading: The Impacts of US Withdrawal from the Kyoto Protocol, *Applied Economics* 35, 651-663.

Brander, J. (1986) Rationales for Strategic Trade and Industrial Policy, in *Strategic Trade Policy and the New International Economics*, ed. P. Krugman. Cambridge. MA: MIT Press.

Brander, J. and B. Spencer (1981) Tax and the Extraction of Foreign Monopoly Rent under Potential Entry, *Canadian Journal of Economics* 14, 371-389.

Brander, J. and B. Spencer (1984) Tax Protection and Imperfect Competition, in *Monopolistic Competition and International Trade*, ed. H. Kierzkowski. Oxford: Oxford University Press.

Brander, J. and B. Spencer (1985) Export Subsidies and International Market Share Rivalry, *Journal of International Economics* 18, 83-100.

Burniaux, J.-M. and T. P. Truong (2002) GTAP-E: An Energy-Environmental Version of the GTAP Model. GTAP Technical Paper, No.16.

Criqui, P., S. Mima, and L. Viguier (1999) Marginal Abatement Costs of CO2 Emission Reductions, Geographical Flexibility and Concrete Ceilings: An Assessment Using the POLES Model, *Energy Policy* 27, 585-601.

Dixit, A. (1984) International Trade Policy for Oligopolisitc Industries, *Economic Journal* 94 (supplement), 1-16.

Eaton J. and G. Grossman (1986) Optimal Trade and Industrial Policy under Oligopoly, *Quarterly Journal of Economics* 101, 383-406.

Evans, M. (2003) Emissions Trading in Transition Economies: the Link between International and Domestic Policy, *Energy Policy* 31, 879V886.

Hwang, H.-S. and C.T. Schulman (1993) Strategic Non-Intervention and the Choice of Trade Policy for International Oligopoly, *Journal of International Economics* 34, 73-93.

Kainuma, M., Y. Matsuoka, and T. Mortia (1999) Analysis of Post-Kyoto Scenarios: The Asian-Pacific Integrated Model, *The Energy Journal, Special Issue on the Cost of the Kyoto Protocol: A Multi-Model Evaluation*, 207-221.

Klepper, G. and S. Peterson (2005) Trading Hot-Air: The Influence of Permit Allocation Rules, Market Power and the US Withdrawal from the Kyoto Protocol, *Environmental and Resource Economics* 32, 205-228.

Krugman, P. (1984) Import Protection as Export Promotion: International Competition in the Presence of Oligopoly and Economies of Scale, in *Monopolistic Competition and Product Differentiation and International Trade*, ed. H. Kierzkowski. Oxford: Oxford University Press.

OECD (1999) *Action against Climate Change: The Kyoto Protocol and Beyond*, Paris: Organization for Economic Co-operation and Development.

Persson, T.A. and C. Azar (2003) The Cost of Meeting the Kyoto Protocol: Dealing with the Carbon Surplus in Russia and the Ukraine, *Management of Environmental Quality: An International Journal* 14, 488-507.

Rehdanz, K. and R. Tol (2005) Unilateral Regulation of Bilateral Trade in Greenhouse Gas Emission Permits, *Ecological Economics* 54, 397-416.

Rose, A. and B. Stevens (1993) The Efficiency and Equity of Marketable Permits for CO2 Emissions, *Resource and Energy Economics* 15, 117-146.

Sager, J. (2003) An Analysis with the CERT Model of the FSU Market Power in the Carbon Emissions Trading Market, *Environmental Modeling and Assessment* 8, 219-238.

Spencer, B. and J. Brander (1983) International R&D Rivalry and Industrial Strategy, *Review of Economic Studies* 50, 707-722.

Westskog, H. (1996) Market Power in a System of Tradeable CO2 Quotas, *The Energy Journal* 17, 95-103.

Weyant, J. (Ed.) (1999) The Cost of the Kyoto Protocol: A Multi-Model Evaluation, *The Energy Journa*l, special issue.

Potential Cost Savings from Internal/External SO_2 Emissions Trading in the Korean Electric Power Industry

Myunghun Lee*

Abstract

The cap and trade system can dramatically reduce the impact of the tightening greenhouse gas emissions standards on industrial productivity. Korea plans to introduce an emissions trading scheme in the near future. To measure the system's cost-saving effects, it is necessary to calculate firms' marginal abatement costs for greenhouse gas emissions reductions. In this regard, Shephard's (1970) output distance function approach is appropriate for Korea, where data availability is limited. We first determine the opportunity cost of removing an additional ton of SO_2 in terms of forgone electricity for power generators in the Korean fossil-fueled electric generation industry. Then, by assuming that each power generator is required to reduce SO_2 emissions by one ton, we compute the potential cost savings from internal trading among generators within the same plant and from external trading across plants at prevailing market prices.

*Department of International Trade, Inha University, 253 Yonghyun-dong, Nam-gu, Incheon, 402-751, Korea. Tel.: +82-32-860-7805; Fax: +82-32-876-9328; E-mail: leemh@inha.ac.kr

I. Introduction

To pursue its “low-carbon, green-growth” policy, Korea, a non-annex 1 country, voluntarily and unilaterally announced its own mid-term mitigation goal to reduce greenhouse gas (GHG) emissions by 30% below business as usual (BAU) by 2020. Achieving this objective is challenging because the Korean economy depends heavily on energy-intensive industries such as automobile manufacturing, shipbuilding, steel, and petrochemicals.[1] Thus, minimizing the impact of greenhouse gas abatement costs incurred by industries is crucial to the successful the “low-carbon, green-growth” policy.

The emissions trading system, a market-based instrument for pollution control, makes it possible for firms to minimize their compliance costs. The government issues emission permits (i.e., pollution rights) to firms within the emissions target, and those emission permits can be traded among firms. High-cost firms are likely to buy permits from those who emit less if the market price is below the abatement cost. Hahn and Hester (1989) found that the U.S. saved up to $13 billion in abatement costs by introducing its emissions trading system (authorized by the 1970 Clean Air Act).

Korea plans to launch a three-year pilot GHG emissions trading scheme in 2010, which is designed to reduce emissions by 1 to 2% below the annual average emissions over the 2005-07 period. Participating organizations include local governments, public organizations, and private firms (including retailers). The Korea Exchange (KRX) would serve as a platform for emissions trading. For the successful development and operation of this system, it is critical to carefully examine the extent to which emissions trading can help reduce abatement costs.

Atkinson and Lewis (1974) derived cost savings from particulate emissions reductions and the attainment of certain ambient air quality in the St. Louis region by using least cost strategies. They found that the existing strategy was 10 times more expensive than the least-cost strategy. Hahn and Noll (1982) determined that 25 SO_2 pollution sources in the LA region would have saved $10 to $23 million by emissions trading. As summarized in Table 1, a number of studies have measured potential cost savings from taking economic incentive approaches.

Many of these studies, using linear programming, have assumed that economic incentives would result in least cost outcomes. However, Atkinson and Tietenberg (1991) suggested that

[1] Energy-intensive industries account for 8% of Korea’s GDP, which is much higher than 5.8% for Germany, 5.4% for Japan, and 3.9% for the U.S.

emissions trading systems would fail to achieve potential cost savings because of limitations imposed by real regulations. In addition, many studies have not taken into account the possibility that the regulatory cost impact may be influenced by the characteristics of production structure such as input substitutability. If fossil fuels and capital are strongly substitutable, then compliance costs may be lower than otherwise.

Therefore, it is desirable to estimate the production function or alternatively a dual cost function in terms of capturing actual abatement costs. Perl and Dunbar (1982) showed that abatement costs for the power plant industry can be reduced by 36.6% on average by implementing SO_2 emissions trading. Gollop and Roberts (1985) suggested that regional SO_2 trading may enable power plants to reduce abatement costs by as much as 47%. These two studies took advantage of a dual cost function.

The present paper assumes that emissions trading is allowed among power plants constrained by SO_2 regulation. To determine how market prices are determined and who buys or sells emission permits, it is necessary to investigate plants' cost structure for pollution abatement. Using Shephard's (1970) output distance function, we determine the shadow price of SO_2, defined as the opportunity cost of abating one ton of SO_2 in terms of forgone electricity, for 12 fossil-fueled power plants (40 generators).[2] Then, by requiring each generator to reduce SO_2 emissions by one ton, we compute the potential cost savings from internal trading among generators within the same plant and from external trading across plants at prevailing market prices.

The rest of this paper proceeds as follows. Section II defines the output distance function and derives the shadow price of SO_2. Section III presents the data and discusses the empirical results. Section IV computes the gains from internal and external emissions trading, and Section V concludes.

II. The Model

Consider a power plant that generates electricity (q) and SO_2 (s) as a by-product of fuel

[2] Two of the major advantages of the distance function over the cost function are as follows: 1) the maintained hypothesis of cost minimization is not imposed and 2) information on input prices and specific regulatory constraints are not required (Grosskopf et al., 1995; Lee, 2007). Thus, the distance function is suitable for studying Korean industries for which limited data are available.

burning using three inputs: capital (k), labor (l), and fuel (f). Then the production technology is defined as $P : R_+^3 \rightarrow 2^{R_+^2}$. Denoting the output vector and input vector as y = (q, s) and x = (k, l, f), respectively, the output set $P(x)$ includes all y that are technically feasible with x. Plants subject to SO_2 emission constraints are not able to abate SO_2 emissions without any cost burdens. That is, they incur the opportunity cost of reduced electricity production resulting from the diversion of some inputs for pollution abatement efforts. We assume that the production technology satisfies the weak disposability, which implies that if $y \in P(x)$, then $\lambda y \in P(x)$ for $\lambda \in [0,1]$.[3]

Following Färe et al. (1993) and Coggins and Swinton (1996), we introduce Shephard's (1970) output distance function defined over $P(x)$, which measures the maximal proportional inflation of y required to reach the technically efficient frontier of $P(x)$ with x unchanged:

$$D(x, y) = \inf\{\mu : (y / \mu) \in P(x)\}, \quad (1)$$

where $D(x, y) \leq 1$ and $D(x, y) = 1$ indicates that firms operate on the boundary of $P(x)$. Note that $\partial D(\cdot) / \partial x \leq 0$, $\partial D(\cdot) / \partial q \geq 0$, and $\partial D(\cdot) / \partial s \leq 0$.

The revenue function is defined as the maximized revenue constrained to the value of the output distance function: $R(x, r) = \sup_y \{ry : D(x, y) \leq 1\}$, where r = (r_q, r_s) is a vector of undeflated shadow output prices. A dual output distance function to the revenue function is defined as (Shephard, 1970)

$$D(x, y) = \sup_r \{ry : R(x, r) \leq 1\}. \quad (2)$$

Following Färe et al. (1993), we obtain the following relationship by applying the envelop theorem on the first-order condition for the Lagrangian problem for revenue maximization:

$$r = R(x, r) \cdot \nabla_y D(x, y), \quad (3)$$

where ∇ is the partial differential operator. From (2), we have $D(x, y) \equiv r^*(x, y) \cdot y$, where r^* is

[3] The strong disposability of technology holds if $z \leq y \in P(x)$; then $z \in P(x)$. Färe and Pasurka (1986) and Zaim and Taskin (2000) compared the efficiency of production technologies for weak disposability and strong disposability.

the vector of revenue-maximizing output prices. Differentiating with respect to y yields $\nabla_y D(x,y) = r^*(x,y)$. Substituting this into (3) gives

$$r = R(x,r) \cdot r^*(x,y). \tag{4}$$

Provided that the market price of electricity, r_q^0, equals its shadow price, the shadow price of SO_2, defined as the opportunity cost of abating an additional unit of SO_2 in terms of forgone electricity, can be calculated as

$$r_s = r_q^0 \cdot \frac{\partial D(x,y)/\partial s}{\partial D(x,y)/\partial q}. \tag{5}$$

To obtain the marginal abatement cost of SO_2, which is given (5), the output distance function is specified in a translog functional form as follows:

$$\begin{aligned} \ln D(x,y) = \alpha_0 + \sum_x \alpha_x \ln x + \sum_y \alpha_y \ln y + \frac{1}{2}\sum_x \sum_{x'} \gamma_{xx'} \ln x \ln x' \\ + \frac{1}{2}\sum_y \sum_{y'} \gamma_{yy'} \ln y \ln y' + \sum_x \sum_y \beta_{xy} \ln x \ln y, \\ x, x' = k, l, f, \; y, y' = q, s. \end{aligned} \tag{6}$$

Following Aigner and Chu (1968) and Färe et al. (1993), we use a linear programming technique for estimating (6). The constrained maximization is pursued as follows:

$$\begin{aligned} & Max \sum_n [\ln D(x^n, y^n) - \ln 1]) \\ & s.t. \ln D(x^n, y^n) \le 0, \\ & \partial \ln D(x^n, y^n) / \partial \ln x^n \le 0, \\ & \partial \ln D(x^n, y^n) / \partial \ln q^n \ge 0, \\ & \partial \ln D(x^n, y^n) / \partial \ln s^n \le 0, \\ & \sum_y \alpha_y = 1, \sum_{y'} \gamma_{yy'} = \sum_y \beta_{xy} = 0, \\ & \gamma_{xx'} = \gamma_{x'x}, \gamma_{yy'} = \gamma_{y'y}, \end{aligned} \tag{7}$$

where n indicates the observations; the first constraint indicates the range of values of the output distance function; the second through fourth ones correspond to monotonicity conditions; the fifth one is imposed for linear homogeneity in outputs; and the last one is given for symmetry.

III. Empirical Results

The data consist of 22 generators in coal-fired power plants and 18 generators in oil-fired power plants that were operating in 1998. The coal-fired plants include Yosu #1 (2 generators), Samchonpo (6), Taean (4), Boryeong (6), and Hadong (4); the oil-fired plants include Busan (2), Ulsan #1 (6), Ulsan #3 (2), Yosu #2 (1), Pyongtaek (4), Namjeju (2), and Bukjeju (1). The electricity output (q) and the capital input (k) are measured in GWh and MW power capacity. The fuel input (f), measured in Kcal, is obtained by using the thermal efficiency calculation formula. The labor input (l) for each generator (i.e., the number of employees assigned to each generator) is calculated according to the power capacity of the generator. Most of the data are reported in the *Business Statistics* (published by Korea Electric Power Corporation). The electricity price (r_q) is the average sales prices, and SO_2 emissions (s) are estimated by using sulfur emission factors by fuel type.[4] The descriptive statistics for those variables are reported in Table 2.

Table 3 presents the parameter estimates for (6), which are obtained by solving the linear programming problem, (7).[5] The values of the output distance function for individual generators are calculated by substituting these estimates into (6). As shown in Table 4, their values vary from 0.938 to 1 (an average of approximately 0.984), indicating that electricity generation, on average, could have increased by approximately 1.6% if the plants had operated on the boundary of production technology. The average value of distance for oil generators (with relatively low standard deviation) is greater than that for coal generators by 0.9 percentage points.

[4] Sulfur emission factors by fuel type are as follows: diesel oil, 17S; bunker-C oil, 19S; bituminous coal, 19S; and LNG, 0.01S. Here, S is sulfur content (%), and oil, coal, and LNG are measured in kg/kl, kg/ton, and kg/1000m^3, respectively.

[5] To estimate the parameters, the LINGO software package is used.

As reported in Table 4, the estimated shadow prices of SO_2 from (5) show that the generators, on average, pay approximately 500,000 won to abate one ton of SO_2 emissions (ranging from 6,000 to 2 million won). In terms of these shadow prices by fuel type, the average values and their standard deviations for oil generators are greater than those for coal generators by approximately 3.5 times and 5 times, respectively.[6] Because the sulfur content standard for fuel oil became more stringent since 1982, the plants were required to purchase expensive low-sulfur oil to independently meet SO_2 emissions targets.[7]

Suppose that the regulatory agency requires each generator to reduce SO_2 emissions by one ton. If these fuel generators are allowed to engage in emissions trading, the oil generators benefit more from trading than the coal generators. Given that market equilibrium prices are determined between upper and lower shadow prices, gains from trading, which are the differences between shadow prices, increase as their standard deviations become higher.

IV. Gains from Internal and External Trading

By assuming a mandatory one-ton reduction in SO_2 emissions for each individual generator, we calculate the potential gains from internal trading among generators within the same plant for seven plants: Samchonpo, Taean, Boryeong, Hadong, Ulsan #1, Ulsan #3, and Pyongtaek. As shown in Table 5, the marginal abatement costs for the six generators at the Samchonpo plant vary from 0.31 to 0.52 million won. On average, each generators pay 0.4 million won to remove one ton of SO_2 emissions. Under this scenario, Samchonpo can maximize cost savings from internal trading by assigning its six-ton reduction target to the generator that abate emissions at the lowest cost. Thus, because it costs 0.31 million won per ton to abate six tons of SO_2, Samchonpo can save up to 0.09 million won per generator (i.e., 0.4 minus 0.31).

Taean has four generators; their abatement costs range from 0.41 to 0.48 million won. If the lowest cost generator (i.e., 0.41 million won per ton) abates four tons (the plant’s target), Taean can save approximately 0.03 million won per generator. Variations in abatement costs among Boryeong’s six generators are similar to those for Samchonpo; each generator at

[6] Coggins and Swinton (1996) suggested that the variation in SO_2 shadow prices may be dependent on the vintage of plants, coal sources, scrubbers, and types of boilers.
[7] The sulfur content standard for heavy oil was tightened from 4.0% to 1.6% in 1981, 1.0% in 1993, 0.5% in 1997, and 0.3% in 2001.

Boryeong can save as much as 0.1 million won through internal trading. Hadong has four generators (0.39 to 0.53 million won); Hadong can save 0.06 million won per generator.

Ulsan #3 has two oil-fired generators that pay 0.33 million won and 0.51 million won to cut one ton of SO_2, respectively. If Ulsan #3 uses the lowest cost generator (0.33 million won per ton) to reduce two tons of SO_2 emissions, it can save 0.18 million won (or 0.09 million won per generator). Ulsan #1 has six oil-fired generators; the abatement costs range from 0.7 to 1.67 million won, and the weighted average abatement cost is 1.48 million won. Because the abatement costs vary widely across the generators, the gains from internal trading can be substantial: 0.65 million won per generator. Compared with Ulsan #1, Pyongtaek has a higher average abatement cost (1.77 million won), but it has a lower standard deviation (1.62 to 1.9 million won). Pyongtaek's total gain can be 0.13 million won per generator.

If a generator at a particular plant could trade emissions with another generator at a different plant (i.e., if generators engage in external trading as well as internal trading), would there be further reductions in abatement costs? In general, external trading is expected to bring about more dramatic cost savings because the variation in abatement costs should be wider across plants than within plants. However, the U.S. experience reveals that internal trading is more widely observed probably because of high transaction costs and system uncertainties in external trading (Turner et al., 1993).

In the present paper, to measure the additional gains from shifting some emissions from internal trading to external trading, we first assign the six plants to three geographic regions according to their location and then examine the range of market prices by region to allow emissions trading among the plants. Plants typically rely mainly on internal trading. However, if they expect additional gains through external trading, they may switch from internal to external trading. In such a situation, a one-ton external trading transaction is accompanied by one less one-ton internal trading transaction.

Table 6 presents the marginal abatement costs for individual generators belonging to the six plants, of which two plants are located in each of three provinces: Gyeong-Nam, Chungcheong, and Ulsan. For Gyeong-Nam, we first consider a case in which the market prices for one ton of emissions range between 0.363 and 0.391 million won; let the price be 0.377 million won, the mean of the two prices. Then the two tons are likely to be traded between Samchonpo and Hadong because Samchonpo's last generator (the lowest cost generator) is able to realize additional gains by shifting from internal trading with the fourth and fifth generators (in terms of the magnitude of abatement costs) to external trading with

Hadong’s the last two generators. Samchonpo, which can save up to 0.09 million won through internal trading, can save as much as 0.138 million won through external trading (i.e., Samchonpo is paid 0.377 million won for one ton of emissions that costs 0.308 million won to remove); thus, the additional benefit is 0.048 million won. Hadong is also better off by trading externally in that it can lower its abatement cost by 0.028 million won; that is, it can abate two tons at 0.377 million won per ton, not 0.391 million won. Table 7 reports the estimates of the additional gains that each plant can realize by switching from internal to external trading (under the likely range of market prices for external emissions trading by region).

If market prices range from 0.343 to 0.363 million won, then one ton will be traded between Samchonpo and Hadong. Suppose that the price is set at 0.353 million won. Samchonpo’s last generator can earn an extra 0.01 million won by abating the one ton allocated to Hadong instead of giving up the fifth generator’s quota, and Hadong’s last generator can abate one ton at 0.038 million won below its cost. If market prices are less than 0.343 million won, Samchonpo does not gain from external trading, and consequently, it will engage only in internal trading.

Let us examine Chungcheong, in which Taean and Boryeong are engaged in external trading. Because Boryeong’s abatement cost is lower than that of Taean, Boryeong acts as the seller, and Taean becomes the buyer under the marketable emission permit scheme. Because the market prices range from 0.368 to 0.41 million won, the two plants trade one ton of emissions. If one ton is traded at 0.389 million won, both Taean and Boryeong can gain 0.021 (i.e., 0.41 minus 0.389 and 0.389 minus 0.368) million won by switching from internal to external trading. In Ulsan, Ulsan #1 sells emission permits. Consider market prices ranging from 0.511 to 0.7 million won, which makes a one-ton trade possible between Ulsan #1 and Ulsan #2. At the mean of lower and upper prices, both plants can gain approximately 0.09 million won by trading. As seen in Table 7, Ulsan is superior to other provinces in terms of not only cost saving effects of internal trading but also the extent of additional gains from external trading.

V. Conclusions

To minimize the impact of GHG emissions regulation on the industrial sector, Korea plans to introduce an emissions trading scheme in the near future. In this regard, for the successful development and operation of this scheme, it is critical to carefully examine the extent to which emissions trading can help reduce abatement costs. By allowing power plants in the Korean electric generation industry to trade SO_2 emissions both within the same plant and across different plants, we determined the shadow price of SO_2, which is equivalent to the marginal abatement cost, for 12 power plants (40 generators). The estimates of shadow prices of one ton of SO_2 ranged from 6,000 to almost 2 million won across the generators.

By requiring the generators to reduce SO_2 emissions by one ton, we computed the potential cost savings from internal emissions trading between generators within the same plant for seven plants. The maximum cost savings from internal trading for individual plants varied from 0.03 to 0.65 million won per generator. We then calculated the potential cost savings from external emissions trading across plants at prevailing market prices. The results indicate that with no additional transaction costs, plants can realize additional gains through external trading. The comparison of three provinces (two plants in each region) suggests that Ulsan may gain the most by shifting some emissions from internal trading to external trading.

References

Aigner, D.J. and S.F. Chu (1968), "On estimating the industry production function," *American Economic Review* 58, 826-839.

Atkinson. S.E. and D.H. Lewis (1974), "A cost effective analysis of alternative air control strategies, " *Journal of Environmental Economics and Management* 1, 237-250.

Atkinson, S. E. and T. Tietenberg (1991), "Market failure in incentive-based regulation: the case of emissions trading," *Journal of Environmental Economics and Management* 21, 17-32.

Coggins, J.S. and J.R. Swinton (1996), "The price of pollution: a dual approach to valuing SO_2 allowance," *Journal of Environmental Economics and Management* 30, 58-72.

Färe, R., C.A.K. Lovell, and S. Yaisawarng (1993), "Derivation of shadow prices for undesirable outputs: a distance function approach," *Review of Economics and Statistics* 75, 374-380.

Färe, R. and C. Pasurka (1986), "Effects on relative efficiency in electric power generation due to environmental controls," *Resources and Energy* 8, 167-184.

Gollop, F.M. and M.J. Roberts (1985), "Cost-minimizing regulation of sulfur emission: regional gains in electric power," *Review of Economics and Statistics* 67, 81-90.

Grosskopf, S., K. Hayes, and J. Hirschberg (1995), "Fiscal stress and production of public safety: a distance function approach," *Journal of Public Economics* 57, 277–296.

Hahn, R and G. Hester (1989), "Where did all the markets go? An analysis of EPA's emission trading program," *Yale Journal of Regulation* 6, 109-53.

Hahn, R.W. and R.G. Noll (1982), "Designing a market for tradeable emissions permits," in W. A. Magat (ed.), *Reform of Environmental Regulation*, Cambridge, MA: Ballinger Publishing Company.

Hailu, A. and T.S. Veeman (2000), Environmentally sensitive productivity analysis of the Canadian pulp and paper industry, 1959-1994: an input distance function approach, *Journal of Environmental Economics and Management* 40, 251-274.

Lee, M. (2007), "Measurement of the in situ value of exhaustible resources: an input distance function", *Ecological Economics* 62, 490-495.

Perl, L.J. and F.C. Dunbar (1982), "Cost effectiveness and cost-benefit analyses of air quality regulations," American Economic Review 72, 208-213.

Shephard, R.W. (1970), Theory of Cost and Production Functions, Princeton University Press, Princeton.

Turner, R.K., D. Pearce, and I. Bateman (1993), Environmental Economics: An Elementary Introduction, Johns Hopkins University Press, Baltimore.

Zaim, O. and F.Taskin (2000), “Environmental efficiency in carbon dioxide emissions in the OECD: a non-parametric approach,” *Journal of Environmental Management* 58, 95-107.

Table 1: Quantitative Studies of Potential Savings from Economic Incentives

Pollutant Controlled	Author (Year)	Geographic Area	Command and Control Approach	Ratio of CAC to Market-Based Approach
Hydrocarbons	Maloney & Yandle (1984)	DuPont facilities in U.S.	Uniform percent reduction	4.15
Nitrogen dioxide	Seskin *at al.*(1983)	Chicago	Proposed RACT regulations	14.4
Nitrogen dioxide	Krupnick (1986)	Baltimore	Proposed RACT regulations	5.9
Particulates (TSP)	Atkinson & Lewis (1974)	St. Louis	SIP regulation	6.0
Particulates (TSP)	McGartland (1984)	Baltimore	SIP regulations	4.18
Particulates (TSP)	Spofford (1984)	Lower Delaware Valley	Uniform percent reduction	22.0
Particulates (TSP)	Oates *et al.*(1989)	Baltimore	Equal proportional treatment	4.0 at 90 ug/m3
Reactive organic gases and NO2	SCAQMD (1992)	Southern California	Best Available Control Technology	1.5 in 1994 1.3 in 1997
Sulfur dioxide	Roach *et al.*(1981)	Four Corners Area	SIP regulation	4.25
Sulfur dioxide	Spofford (1984)	Lower Delaware Valley	Uniform percent reduction	1.78
Sulfur dioxide	ICF Resources (1989)	United States	Uniform emission limit	5.0
Sulfates	Hahn and Noll (1982)	Los Angeles	California emission standards	1.07
Chlorofluorocarbons	Palmer et al. (1980); Shapiro and Warhit (1983)	United States	Proposed emission standards	1.96
All?	Toman et al. (1994)	Poland	EC and German standards	1.1 to 1.2
Sulfur dioxide	Haklos (1994)	Europe	Uniform percent reduction	1.42
Ozone	Hahn (1995)	United States	Vehicle mandate in CA and North-east	1.3 (NE only) 2.0 (CA + NE)

Source: EPA Home/NCEE/Publications/Browsable Reports/Economic Incentives for Pollution Control/ Table1. Table 3-1.

Table 2: Descriptive Statistics

Variable	Unit	Average	S.D.	Max.	Min.
q	10^3 GWh	2.027	1.524	4.022	0.063
s	10^3 tons	6.671	5.444	13.965	0.155
k	MW	364	173	603	10
l	persons	92	44	154	3
f	10^{12} Kcal	4.478	3.296	8.916	0.160

Table 3: Parameter Estimates

Parameter	Estimate	Parameter	Estimate
α_0	-37.4247	β_{kf}	-1.7168
α_q	-0.1742	β_{ll}	-49.4778
α_s	1.1742	β_{lf}	1.8255
β_k	53.6713	β_{ff}	-0.0343
β_l	-58.4242	γ_{kq}	0.3044
β_f	0.9967	γ_{ks}	-0.3044
α_{qq}	0.1200	γ_{lq}	-0.3288
α_{qs}	-0.1200	γ_{ls}	0.3288
α_{ss}	0.1200	γ_{fq}	0.0240
β_{kk}	-41.7705	γ_{fs}	-0.0240
β_{kl}	45.4932		

Table 4: Value of the Output Distance Function and the Estimation of Marginal Abatement Cost for SO_2

Generator Type (No.)	Value of Distance				Marginal Abatement Cost (thousand won/ton)			
	W.A.[a]	S.D.	Max.	Min.	W.A.[b]	S.D.	Max.	Min.
Coal (22)	0.9834	0.0208	1.0000	0.9389	420	140	534	8
Oil (18)	0.9927	0.0071	1.0000	0.9756	1,525	709	1903	6
Total (40)	0.9845	0.0174	1.0000	0.9389	512	577	1903	6

a: weighted by electricity output.

b: weighted by SO_2 emissions.

Table 5: Potential Cost Savings from Internal Trading by Plant

Plant	Number of Generators	Marginal Abatement Cost (thousand won/ton)				Cost Saving (won/ton)[b]
		W.A.[a]	S.D.	Max.	Min.	
Samchonpo	6	402	78	520	308	92,422
Taean	4	443	33	489	410	31,883
Boryeong	6	450	74	534	346	100,068
Hadong	4	461	63	532	391	61,434
Ulsan #3	2	433	125	511	334	88,788
Ulsan #1	6	1,488	378	1,677	700	655,761
Pyongtaek	4	1,744	127	1,903	1,620	135,733

a: weighted by SO_2 emissions.

b: amount per generator.

Table 6: Marginal Abatement Costs for Individual Generators Belonging to Plants by Region

Region	Plant	Marginal Abatement Cost by Generator (thousand won/ton)									
Gyeong-Nam	Samchonpo		520		457		414		363	343	308
	Hadong	532		473		417		391			
Chung-cheong	Taean			489			441	427	410		
	Boryeong	534	501		473	453				368	346
Ulsan	Ulsan #1							511	334		
	Ulsan #3	1677	1628	1543	1476	1112	700				

Table 7: Range of Market Prices for External Trading and the Estimate of Additional Gains by Plant

Plant	Market Price (p_s; million won/ton): volume (ton)	
	$0.363 < p_s < 0.391$: 2	$0.343 < p_s < 0.363$: 1
Samchonpo	0.02 < · < 0.076	0 < · < 0.02
Hadong	0.056 > · > 0	0.048 > · > 0.028
	$0.368 < p_s < 0.41$: 1	
Taean	0.042 > · > 0	
Boryeong	0 < · < 0.042	
	$0.0511 < p_s < 0.7$: 1	
Ulsan #1	0 < · < 0.189	
Ulsan #3	0.189 > · > 0	

COMPARISON OF META ENVIRONMENTAL EFFICIENCY AND PRODUCTIVIY IN KOREAN AND CHINISE MANUFACTURING INDUSTRIES

Sang-Mok Kang [1], Moon-Hwee Kim [2]

Professor, Department of Economics, Pusan National University, 30 Jangjeon-dong, Geumjeon-gu Busan 609-735, KOREA, smkang@pusan.ac.kr

Ph.D candidate, Department of Economics, Pusan National University, 30 Jangjeon-dong, Geumjeon-gu Busan 609-735, KOREA, hwee@pusan.ac.kr

ABSTRACT

The purpose of this study is to analyze the individual technical efficiency, meta- technical efficiency, individual productivity change, and meta-productivity change of the manufacturing industries in Korea and China. In addition, we estimate them as separating the case including the environmental factor from the case excluding the environmental factor. The individual technical efficiencies and meta-technical efficiencies of the manufacturing industries in two countries are different from each other, and the latter is lower than the former in both countries. However, the difference between two kinds of technical efficiencies of both countries shrank in the case of considering the environmental element. The Korean manufacturing industries are higher than those of China in terms of meta-productivity change. This implies that the manufacturing industries in Korea have contributed to the rapid extension of the frontier annually. When considering the environmental factor, the meta-productivity change decreases more than the individual productivity change in both countries. However, the diminishing level of China is bigger than that of Korea. This means that Korea is in the advantageous position when adding the pollution abatement activity to the productivity. Thus, this study shows that we might distort the reality when measuring the technical efficiencies and productivity changes of manufacturing industries in both countries based on the general frontier not on the meta-frontier.

KEY WORDS: Meta-Technical Efficiency, Technical Gap, Meta-productivity Change, Productivity Gap, DEA

1. INTRODUCTION

China, whose annual economic growth rate has been recorded at approximately ten percent since its change to reform and openness, is emerging as 'the world's largest manufacturing country.[1] The fact that China has arisen as ‘the world’s factory’ gives a wake-up call to Korea because the manufacturing industry is still important in leading Korean economic growth. That is, not only this rapid growth of China as well as the rapidly changing world situation is an opportunity and a threat to Korea simultaneously. China has upgraded its manufacturing industries such as the heavy and chemical industry, the electrical and electronic industry, and the automobile industry, which are also the main manufacturing industries of Korea. Moreover, the technical gap between Korea and China has decreased gradually since diplomatic relations were established between the two countries. Therefore, Korea is in the situation to consider measures such as productivity improvement based on the sense of this crisis.

The competition among manufacturing industries is influenced by various factors such as price and the quality of products. The technical efficiency and productivity are included in one of indices representing the competition in terms of the efficient use of resources. The technical efficiency measures the relative ratio between the case of achieving the maximum output, and that of not achieving the maximum output, under the given input; that is,

[1] *The Financial Times* reported that China will emerge as the world's largest manufacturing country in 2025 year and will outpace the US. as a result. This is caused by the ratio of production to the world's manufacturing industries increased from 15% in 2008 to 34.7% in 2025 according to the research of Global Insight which is an economic consultant, located in Washington (http://www.ft.com/cms).

it indicates the ratio of the actual production point over the production point on the production frontier over all the periods. Productivity does not mean just the amount that was produced but the ratio of output produced to the input used. It means that productivity is an important element influencing a firm's sustainable growth and competition.

As interest in the environment has increased sharply both at home and abroad recently, considering the environmental element has been widely recognized as being more reasonable than using the method without the environmental element when measuring productivity growth. Hence, this study intends to estimate the environmental productivity including pollution and investigate the environmental productivity gap of the manufacturing industries between the two countries through a comparison of the environmental productivity with the traditional productivity excluding pollution in order to find the meaning of the environmental productivity. The traditional productivity can be derived by deducting the term pollution from the environmental productivity. In this paper, we intend to analyze the technical efficiency, technical gap, and productivity gap between Korea and China empirically using the meta-frontier concept. If the technical efficiencies and productivities of the manufacturing industries in Korea and China are measured, it is difficult to compare them objectively because the frontiers between both countries are different; however, if we include the frontiers of the two countries, it will be advantageous to compare the relative advantage through the meta-technical efficiencies and meta-productivities. The concept of the meta-frontier has been used to compare the technical efficiency of observations which are in different groups such as industries, regions, or countries.

Battese and Rao (2002) first introduced the concept of the meta-frontier to estimate the technical efficiency and technology gap effects separately, using stochastic frontier analysis (SFA) and the data envelopment analysis (DEA) simultaneously. Jemaa and Dhif (2005) also estimated the technical efficiency and technology gap effects in European countries. O'Donnell et al. (2008) suggested the basic framework to define the meta-frontier and an empirical example of the meta-frontier model through the parametric method as well as the non-parametric method using cross-country's agricultural sector data. Rngsuriyawilboon and Wang (2008) estimated the agricultural productivity of 28 provinces in China by separating it into technical efficiency, technical progress and scale efficiency using the meta-frontier.[2] Chen *et al*. (2009) tried to analyze the regional productivity growth in China for 1996-2004. They divided inland provinces from coastal provinces and investigated regional disparities based on productivity. In this paper, we will examine the technical efficiency, technology gap, and productivity of the manufacturing industries in Korea and China for 2000-2004, introducing the meta-frontier model of Battese and Rao (2002). Their analysis investigates the two different countries that may not have the same technology and the different industries within each of those countries. Therefore, it may create a bias when adopting the existing frontier model. However, when adopting the meta-frontier model, there is an advantage to conceptualizing the differences among these industries as a technology gap. Furthermore, we should try to examine the influence of environmental factors on the competitiveness of the manufacturing industries between the two countries reflecting the fact that an interest in the environment has recently developed. Through this, we expect to confirm which type of business is closer to sustainable growth. This study differs from the previous ones in terms of suggesting the model which combines the meta-frontier model with the frontier model considering an environmental factor. Therefore, this study has significance for being the first to try considering an environmental element on the manufacturing industries between Korea and China while adopting the meta-frontier model based on the DEA. This paper is organized as follows: Section 2 presents a theoretical model of the meta-frontier based on DEA; Section 3 provides the empirical results, and Section 4 presents the conclusion including political implications.

2. THEORETICAL MODEL

[2] Sang-Mok Kang and Sang-kyu Jo(2009)

When explaining the theoretical model, we will explain the measurement of the regional technology and the meta-technology after introducing the relationship between the individual technology and the meta-technology

2.1 The relation between individual technology and meta-technology

In general, technical efficiency means the capacity to produce output by employing the minimum resource, and the measurement of its efficiency is based on the Distance Function theory. Let us consider that production can be produced during the periods, p =1, …, P in regions K, k = 1, …, K and define x ∈ R+N as inputs, y ∈R+M as desirable outputs, and undesirable outputs as b ∈ R+I . Let us assume that the production function, F(x) is as follows:

$$F(x) = \{(y, b): (x, y, b): \in A\} \quad (1)$$

The production possibility set F(x) is the set of input vector and output vector and it produces the set of outputs and the pollution, (y, b), which can be produced from inputs, x.[3] A means technology, which is a means or the activities transforming given inputs into outputs. We define the entire regional technology as the meta-frontier. For instance, if the random output, y, is produced using given input vector, x, in a certain region, (x, y, b) belongs to the meta-frontier, A^*. This means A^k including the random production point, (x, y, b), belongs to the technology in a certain region, is a subset of A^*. It is defined as follows:

$$A^* \supseteq \{A^1 \cup A^2 \cup \ldots \cup A^k\} \quad (2)$$

Equation (2) satisfies the necessary technology axiom since the sub-set (the individual technology) satisfies a technology axiom. That is, meta-technology forms the meta-frontier including these technologies through a convex combination of the technologies in those certain areas. Thus, meta-technology means the existence of technology (A^*), which takes precedence over all technologies.

Each production unit belonging to the region, k, is produced under the individual technology, A (k=1, 2, ..., K). In this study, we will use the Directional Distance Function in order to measure sustainable growth more suitably. The Directional Distance Function provides advantages that can give different directions such as increase (+) or decrease (-) to the desirable output and pollution, respectively. This is defined as follows:

$$\overrightarrow{D_c^k}(x, y, b: -g_x, g_y, -g_b) = \max\{\beta: (y + \beta g_y, b - \beta g_b) \in F_c^k(x - \beta g_x)\} \quad (3)$$

In equation (3), β indicates the concrete level of the Directional Distance Function. When $0 < \beta$, it is inefficient since the observation locates within the frontier. β measures the level of the output which is extendable on the basis of a point on the frontier in order to reach the maximum output from the real output. On the other hand, when $\beta = 0$, it represents being efficient as the observation locates on the frontier. The directional vector, *g*, gives the direction to the desirable output and pollution; here, it gives the direction of increase (+) to the output and the direction of decrease (-) to pollution, respectively.

The meta-directional distance function, based on the meta-technology that contains the frontier based on the individual technology, is defined as follows:

$$\overrightarrow{D_c^*}(x, y, b: -g_x, g_y, -g_b)$$

[3] According to Fare, Grosskopf, and Pasurka (1986), suppose that the pollution set is weak disposability and the output set is strong disposability. The weak disposability of the pollution can be expressed as (y, b) ∈ F(x) and (βy, βb) ∈ F(x) if 0≤β≤1. This represents that the producers should reduce the pollution emission and the production of desirable outputs simultaneously. On the other hand, the strong disposability, producing desirable outputs while reducing the pollution emission freely, can be expressed as (y, b)∈F(x) and (y', b)∈F(x) if ∀y'≤ y.

$$= \max\{\eta : (y + \eta g_y, b - \eta g_b) \in F_c^*(x - \eta g_x)\} \quad (4)$$

Equation (4) is the meta-directional distance function and is integrated by the individual frontiers. The relation between the meta-directional distance function and the individual directional distance function can be expressed as follows:

$$\overrightarrow{D_c^*}(x, y, b) \geq \overrightarrow{D_c^k}(x, y, b), k = 1, 2, \ldots, K \quad (5)$$

Equation (5) derives from the fact that the output set of a certain region is a subset of the output from meta-technology. That is, the technical efficiency of the meta-directional distance function is the same with the frontier or it can also be relatively farther away from the frontier compared to the technical efficiency of the individual directional distance function. When a sign is inequality (< or >) in equation (5), it means there is a technology gap between the individual technology of k and the meta-technology. The technology gap can be represented as follows by using the technical efficiencies based on the individual distance function and the meta-distance function.

$$\overrightarrow{TG_c^k}(x, y, b) = \frac{\overrightarrow{D_c^*}(x,y,b)}{\overrightarrow{D_c^k}(x,y,b)} \quad (6)$$

The technical efficiency of equation (6) can be estimated by the relative ratio between the two technical efficiencies. Of course, equation (6) can also be represented as a multiple of the individual distance function and the technical gap.

2.2 Measurement of the technical efficiency

In general, the distance function can be measured by using a linear program. If we assume that the observations in the regions, k=1,…,K produced, the outputs, y_m, m = 1,…,M and pollutions, b_i , i =1,…,I, the linear program of the individual production unit, k, of an individual technology set, A^k, is defined as follows:

$$D_c^{k'}(x_n, y_m, b_i; -x_n, y_m, -b_i) = \max\beta$$

$$\text{s.t} \sum_{k=1}^{K} z^k y_m^k \geq (1+\beta) y_m^k, m = 1, \ldots, M, k = 1, \ldots, K$$

$$\sum_{k=1}^{K} z^k b_i^k = (1-\beta) b_i^k, i = 1, \ldots, I, k = 1, \ldots, K$$

$$\sum_{k=1}^{K} z^k x_n^k \leq (1-\beta) x_n^k, n = 1, \ldots, N, k = 1, \ldots, K$$

$$z^k \geq 0 \quad (7)$$

The left side in the restricted conditions in equation (7) means the maximum amount of output and the minimum amount of input, the right side in the restricted conditions means the real amount of output and the real amount of input. This restricted conditions satisfied strong disposability and weak disposability for the output and the pollutant, respectively.

Z^k is a weighted density vector. A non-negative density vector represents that the production technology is constant returns to scale.[4] β indicates the concrete value of the directional distance function as the technical efficiency of the directional distance function and has the value from zero(0) to one(1). In equation(7), the optimal solution can be acquired when the outputs and pollution have the directions of g{x(1- β), y (1+ β), b (1- β)}.

The left side in the restricted conditions means each individual observation vector of the input and the output is combined with each weighted vector, and it forms the maximum amount of output and the minimum amount of input. The right side in the restricted conditions means the real amounts of outputs and the real amount of input, respectively. Here, if the left side is equal to the right side, it means that the maximum amount of output is the same as the minimum amounts of inputs. On the other hand, the meta-frontier is formed based on the pooling data integrating

[4] The previous studies mainly assume a certain scale, however, we do not consider the difference accompanied by the different economy scales because the focus in this study is not an economy scale but comparing the technical efficiency and productivity of the manufacturing industries in the two countries.

Korean individual manufacturing industries and Chinese individual manufacturing industries; that is, the linear programming of the meta-frontier is represented as equation (8) since $A^* \supseteq \{A^1 \cup A^2 \cup \dots \cup A^K\}$:

$$D_c^{*}(x_n, y_m, b_i; -x_n, y_m, -b_i) = \max\eta$$

$$s.t \sum_{j=1}^{J}\sum_{k=1}^{k} z^k y_m^k \geq (1+\eta) y_{m_j}^k j = 1, \dots, J, \quad k = 1, \dots, K$$

$$\sum_{j=1}^{J}\sum_{k=1}^{k} z^k b_i^k = (1-\eta) b_i^k, i = 1, \dots, I, k = 1, \dots, K$$

$$\sum_{j=1}^{J}\sum_{k=1}^{k} z^k x_n^k \leq (1-\eta) x_n^k, n = 1, \dots, N, k = 1, \dots, K$$

$$z^k \geq 0 \qquad (8)$$

Equation (8) shows the conditions of maximum output and minimum input integrating individual frontiers. Here, η is the actual value of meta-frontier distance function. The meta-technical efficiency becomes farther away from the meta-frontier because it is much more extended than the frontier in the case of measuring production units with respect to individual frontiers.

2.3 Measurement of individual productivity and meta-productivity

The directional distance function can be defined in the period, p, and the period, p+1, respectively, and it can be used to estimate the technical efficiency in each period. This directional distance function can also be utilized for measuring the productivity change.

This study intends to compare and analyze the general productivity (Malmquist productivity: hereafter M) excluding the pollution, and the environmental productivity (Malmquist-Luenberger productivity: hereafter ML) including the pollution separately.

First, the productivity growth based on the directional distance function ignoring the pollution can be estimated by using Malmquist productivity index, developed by Fare, Grosskopf, Norris and Zhang (1994). The productivity change index, M, can be derived by using four directional distance functions in two different time periods: the directional distance functions in the time period p and p+1 respectively, from the perspective of time period p technology, and the directional distance functions in the time period p and p+1, respectively from the perspective of period p+1 technology. This is derived as equation (9):

$$\overrightarrow{M_p^{p+1}} = \left[\frac{1+\overrightarrow{D_c^p}(x^p, y^p, 0; g^p)}{1+\overrightarrow{D_c^p}(x^{p+1}, y^{p+1}, 0; g^{p+1})} \frac{1+\overrightarrow{D_c^{p+1}}(x^p, y^p, 0; g^p)}{1+\overrightarrow{D_c^{p+1}}(x^{p+1}, y^{p+1}, 0; g^{p+1})}\right]^{\frac{1}{2}} \qquad (9)$$

In equation (9), the direction vector, $g=(-g_x, g_y, 0)$, is the case that does not give the direction of reduction of pollution. It means an increase in productivity between the two periods if the productivity change index, M, is greater than one (1), and it indicates a decline in productivity between two periods if the productivity change index, M, is less than one (1).

After the same fashion, the meta-productivity change index can be derived using the directional distance function defined as meta-technology as equation (10):

$$\overrightarrow{M_p^{*p+1}} = \left[\frac{1+\overrightarrow{D_c^{*p}}(x^p, y^p, 0; g^p)}{1+\overrightarrow{D_c^{*p}}(x^{p+1}, y^{p+1}, 0; g^{p+1})} \frac{1+\overrightarrow{D_c^{*p+1}}(x^p, y^p, 0; g^p)}{1+\overrightarrow{D_c^{*p+1}}(x^{p+1}, y^{p+1}, 0; g^{p+1})}\right]^{1/2} \qquad (10)$$

Equation (10) shows the meta-productivity change index based on the meta-directional distance function which is defined on the basis of the meta-frontier integrated by individual frontiers. The productivity gap can be defined as equation (10) using the productivity change index based on regional industries' frontiers in equation (9) and the meta-productivity change index in equation (10):

$$\overrightarrow{MG} = \frac{\overrightarrow{M_p^{*p+1}}}{\overrightarrow{M_p^{p+1}}} \tag{11}$$

The meta-productivity change estimated from the perspective of the meta-frontier can be divided into the individual productivity and productivity gap. The value of the technology gap can be either less than, or greater than, one (1). That is, since the productivity change is intended to measure the productivity change in two different periods, the meta-productivity change can be either less than, or greater than, the individual regional productivity change.

As we have already seen, the M productivity index represents the case of the productivity change excluding the environmental element. In this study, we try to identify the ML productivity change giving the direction to decrease the amounts of pollution to the alternative M productivity change. First, the productivity change, including the environmental factor based on an individual frontier by employing the directional distance function, is defined as follows:

$$\overrightarrow{ML_p^{p+1}} =$$

$$\left[\frac{1+\overrightarrow{D_c^p}(x^p,y^p,b^p;g^p)}{1+\overrightarrow{D_c^p}(x^{p+1},y^{p+1},b^{p+1};g^{p+1})} \frac{1+\overrightarrow{D_c^{p+1}}(x^p,y^p,b^p;g^p)}{1+\overrightarrow{D_c^{p+1}}(x^{p+1},y^{p+1},b^{p+1};g^{p+1})}\right]^{1/2} \tag{12}$$

$\overrightarrow{ML_p^{p+1}}$ in equation (12) estimates the productivity improvement based on the direction not only to decrease pollution, but also the direction to simultaneously increase output.

If the pollution abatement activities are not reflected as productivity growth as in equation (12), it is possible to underestimate the productivity and give incomplete information about productivity measurement. On the other hand, if the pollution abatement activities are considered as productivity growth, it can give more realistic information about productivity measurement in view of the disposal of output and pollution in the production activity at the same time. If the ML productivity change index is greater than one, it means productivity improvement. However, it means a drop in productivity if the ML productivity change index is less than one. Next, the meta-productivity change can be derived as equation (13) by using the directional distance function which is defined as the meta-technology:

$$\overrightarrow{ML_p^{*p+1}} =$$

$$\left[\frac{1+\overrightarrow{D_c^{*p}}(x^p,y^p,b^p;g^p)}{1+\overrightarrow{D_c^{*p}}(x^{p+1},y^{p+1},b^{p+1};g^{p+1})} \frac{1+\overrightarrow{D_c^{*p+1}}(x^p,y^p,b^p;g^p)}{1+\overrightarrow{D_c^{*p+1}}(x^{p+1},y^{p+1},b^{p+1};g^{p+1})}\right]^{1/2} \tag{13}$$

Equation (13) shows the meta-productivity change on the basis of the meta-frontier which integrates the individual industries' frontiers. If the meta-productivity change is greater than one (1), it means productivity improvement, whereas it means a drop in productivity if the meta-productivity change is less than one. The productivity gap can be defined as follows by using productivity change.

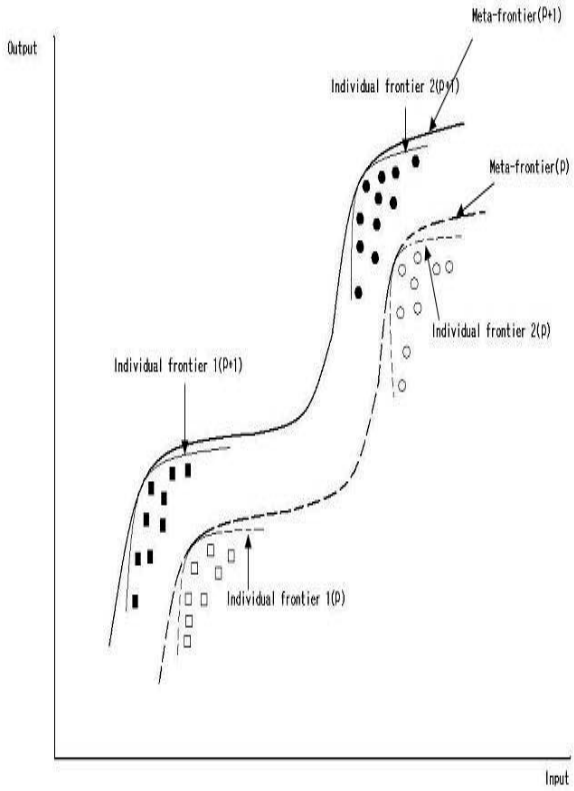
$$\overrightarrow{MLG} = \frac{\overrightarrow{ML_p^{*p+1}}}{\overrightarrow{ML_p^{p+1}}} \tag{14}$$

The meta-productivity change in equation (13) can be decomposed into individual productivity change and productivity gap.

Since productivity change estimates the change in two different time periods, the meta-productivity change can be either greater or less than general productivity change. When the meta-productivity change is greater than the individual productivity change, the productivity gap is greater than one, while the productivity gap is less than one when the meta-productivity change is less than the individual productivity change.

As described above, the relation between the individual technical efficiency and the meta-technical efficiency, and the relation between the individual productivity change and the meta-productivity change are shown in <Figure 1>. <Figure 1> represents the relation between the individual frontier and meta-frontier, the individual productivity change, and the meta-productivity. For the convenience of explanation, let us assume that there are only two individual frontiers. We can measure an individual technical efficiency based on the individual frontier for each first time period (p), respectively, and derive the meta-frontier enveloping the two frontiers. When measuring the technical efficiency based on the meta-frontier, it might differ from the technical efficiency based on the individual frontier. Likewise, the meta- productivity change can be estimated on the basis of the meta-frontier for the two time periods.

Furthermore, general productivity change can be measured on the basis of the individual frontiers between two time periods. The two productivity changes can show which frontier is farther extended between an individual frontier and a meta-frontier during the two time periods.



<Figure 1> the relation between individual frontiers and meta-frontiers

3. DATA AND EMPIRICAL RESULT

We used inputs (labor and capital), outputs (added value), and a pollutant (SO_x) of the manufacturing industries in two countries during 2000-2004. In China, the statistical data of inputs and output and emission amounts are available from the Chinese Statistical Yearbook.[5] In Korea, we used the emission amounts of SO_x from CAPSS (CAPSS: Clean Air Policy Support System). Monthly labor input amounts and capital stock

[5] SO_x can indicate other air pollutants partially but it cannot reflect levels of water and soil pollutants. However, as China includes only the emission amounts of SO_x in the statistical data of pollutants, we use only one pollutant, SO_x. Pollutants that are particularly difficult to treat may require additional cost for disposal. But as general pollutants are usually processed in the same manner, pollutant treatment cost does not vary, regardless of pollutant amounts. That is, pollution prevention facilities must be operated to treat one pollutant at least with the whole process of pollution treatment regardless of the types of pollutants. Sang-Mok Kang et al (2008).

were acquired from the statistical report of mining and manufacturing industries(2002-2005), and SO_x emissions for each manufacturing industry provided by CAPSS, were used. The capital stock of each manufacturing industries in China was estimated by accumulating new investment data through the perpetual inventory method.[6] The capital stock in China was estimated by the perpetual inventory method, which is based on the investment of fixed assets from Chinese Statistical Yearbook. Since there is no available data of capital stock by industry in China, we estimated it through the perpetual inventory method based on new investment. Here, the initial capital stock is estimated by using new investment for initial certain periods and the average growth rate of initial new investment, as in Young (1995).[7] Previous studies such as Young (1995) used the depreciation rate of 6 percent. In this study, we will compare 22 business types in Korea with 16 business types in China. The classification of manufacturing industries in China is different from the standard industry classification in Korea. The manufacturing industries classified into 32 business types are reclassified into 16 so that they are comparable with those of Korea.[8]

<Table 1> shows the individual technical efficiency, the meta-technical efficiency, and the technology gap, which ignore the impact of pollution. The individual technical efficiency excluding the pollution in China (0.879) is higher than that in Korea (0.722). Sang-Mok Kang *et al*. (2008) explained that the Chinese manufacturing industries are more efficient than the Korean manufacturing industries because the costs of location and production in Korea are much higher than those in China. In Korea, both the tobacco industry, and the coke, refined, petroleum products and nuclear fuel manufacturing industry, show the maximum efficiency, 1.000, respectively; wearing apparel and fur products(0.863), leather, luggage and harness (0.816), motor vehicles (0.754), and audio-visual equipment(0.739) are more efficient than the average(0.722). In China, leather and fur manufacturing shows the maximum efficiency and coke, refined, petroleum products and nuclear fuel (0.998), machinery and equipment, electric machinery (0.997), food products and beverages, tobacco (0.968), metal products (0.963), manufacture of plastics (0.940) are more efficient than the average. When it comes to the meta-technical efficiency of Korea, tobacco and comparing the technical efficiency of the manufacturing industries in both countries still show the maximum efficiency. Wearing apparel and fur products (0.795), leather, luggage and harness (0.784), and motor vehicles (0.711) are more efficient than the average. Leather and fur manufacturing still shows the maximum efficiency, and machinery and equipment, electric machinery (0.975), metal products (0.940), coke, refined, petroleum products and nuclear fuel (0.927), food products and beverages (0.902), and manufacture of plastics (0.877) are more efficient than the average (844) in China. It is interesting that coke, refined, petroleum products and nuclear fuel, machinery and equipment, electric machinery, food products and beverages in China are very close to the maximum efficiency when it comes to the

6 Investment in fixed assets from Chinese Statistical Yearbook was used.

7 Industrialization started in China after its reform and movements and the new investment was available from the early 1980s. However, we estimated the amount of new investment by extending the term to the middle of the 1960s and adopting the average growth rate of the new investment in the 1980s in order to bring them roughly into line with Korea. China has invested mainly in the manufacturing industries, especially in the light industry since its reform and openness so the new investment in the most of the light industry is zero or near zero. The estimation formula according to the perpetual inventory method is as follows:

$K(1)=I(1)/(\delta+g)$

in which K(1) is capital stock in the 1st term, I(1) is new investment in the first term, δ is the depreciation rate, and g is the annual growth rate of new investment in the five initial years. Therefore, constant capital stock is calculated by the following formula:

$K(1)=(1-\delta)K(t-1)+I(t), t+2, \dots, T$

The same depreciation rate was applied to consistently analyze capital stock of two countries.

8 In order to compare evenly, it is necessary to unify the statistical data of inputs, outputs, and pollution. In China, the statistical data of inputs and outputs are classified into 16 business types and that of pollution is presented with 32 business types. On the contrary, the manufacturing industries are classified into 23 business types in Korea, with slight difference in each item. Therefore, perfect unification is impossible. Hence, the statistical data of pollution in China is integrated into 16 business types as they are unified into inputs and outputs.

individual technical efficiency, however, the technical efficiency decreased relatively when it comes to the meta-technical efficiency. This means that these types of business are outstanding in terms of the relative technical efficiency within the region, but the technical efficiency decreased a lot in terms of the level of the absolute technical efficiency that integrates Korea with China.

Comparing the technical efficiency of the manufacturing industries in both countries, most of those in China have an advantage, while Korea shows an advantage in the industries such as coke, refined, petroleum products and nuclear fuel industry, chemicals and chemical products, and non-metallic mineral products. When it comes to the technical gap ignoring the environmental factor, while Korea shows maximum economic performance in tobacco industry and coke, refined, petroleum products and nuclear fuel industry, China shows maximum economic performance in wearing apparel and fur products industry.

The meta-technical efficiency is lower than the individual technical efficiency on average in both the Korean manufacturing industries and the Chinese manufacturing industries in terms of the technical efficiency gap excluding the environmental element. However, the gap between the individual technical efficiency (0.722) and the meta-technical efficiency (0.703) in Korea is lower than the gap between the individual technical efficiency (0.879) and the meta-technical efficiency (0.844) in China. The Korean manufacturing industries are annually higher than the Chinese manufacturing industries in terms of the technical efficiency gap excluding the environmental element, being 0.974 and 0.960, on average, respectively. This indicates that the frontier of the individual technical efficiency in Korea is closer to the meta-frontier, and that in China is farther from the meta-frontier. That is, the technical gap shows how far the individual frontier is from the meta-frontier; if the technical gap is one (1), it means that the two frontiers are the same. Thus, the distortion of the individual production frontier in Korean manufacturing industries is smaller than that in Chinese manufacturing industries since the technical gap of Korean manufacturing industries is relatively closer to the meta-frontier. Especially, while the individual frontier and the meta-frontier of tobacco industry and coke, refined, petroleum products and nuclear fuel industry are equal to each other as their the technical gaps are one (1) among Korean manufacturing industries, the technical gap of wearing apparel and fur products is the lowest among Korean ones.

<Table 1> the meta-technical efficiency and technology gap excluding pollution (2000-2004 year)

Types of Industries		Meta	Inv.	TG
Korea	Food Products and Beverages	0.683	0.684	0.999
	Tobacco	1.000	1.000	1.000
	Textiles	0.629	0.631	0.997
	Wearing Apparel and Fur Articles	0.795	0.863	0.921
	Leather, Luggage and Harness	0.784	0.816	0.961
	Wood and Wood Products	0.622	0.622	0.999
	Pulp, Paper and Paper Products	0.626	0.626	0.999
	Publishing, Printing, and Recorded Media	0.656	0.661	0.992
	Coke, Refined, Petroleum Products and Nuclear Fuel	1.000	1.000	1.000
	Chemicals and Chemical Products	0.680	0.680	0.999
	Manufacture of Rubber and Plastics	0.650	0.652	0.998

	Non-metallic Mineral Products	0.628	0.639	0.983
	Basic Metal	0.691	0.696	0.993
	Fabricated Metal Products	0.648	0.658	0.984
	Manufacture of Other Machinery and Equipment	0.688	0.712	0.967
	Other Electric Machinery	0.702	0.711	0.987
	Audio-visual Equipment	0.685	0.739	0.926
	Medical and Precision	0.691	0.702	0.984
	Motor Vehicles	0.711	0.754	0.944
	Other Transport Equipment	0.642	0.664	0.967
	Furniture and Other Manufacturing	0.681	0.691	0.986
	Processing of Recycled Materials	0.690	0.691	0.998
Average		0.703	0.722	0.974
China	Food Products and Beverages, Tobacco	0.902	0.968	0.931
	Textiles	0.778	0.784	0.993
	Leather and Fur Products	1.000	1.000	1.000
	Pulp, Paper and Products	0.736	0.766	0.961
	Publishing, Printing, and Recorded Media	0.681	0.727	0.938
	Coke, Refined, Petroleum Products and Nuclear Fuel	0.927	0.998	0.929
	Chemicals and Chemical Products	0.632	0.675	0.936
	Medical Products	0.686	0.692	0.992
	Chemical Fiber	0.832	0.865	0.962
	Manufacture of Rubber	0.778	0.797	0.976
	Manufacture of Plastics	0.877	0.940	0.933
	Non-metallic Mineral products	0.519	0.575	0.902
	Refining and Rolling of Metal	0.772	0.799	0.967
	Refining and Rolling of Non-metal	0.829	0.862	0.961
	Metal products	0.940	0.963	0.977
	Machinery and Equipment, Electric Machinery	0.975	0.997	0.978
Average		0.844	0.879	0.960

1) Meta and Inv. in this table mean meta-technical efficiency and individual technical efficiency, respectively while TG means technology gap.

2) The average was measured by giving a weighted value based on the output (added value).

3) The technical efficiency is efficient if it is zero, however, we use its reciprocal in order to avoid confusing it with the value of productivity (the technical efficiency has the value from zero to one, and it shows being efficient if it is one in this table).

<Table 2> shows the productivity growth and the productivity gap of the manufacturing industries in the two countries during the same period. While the technical efficiency compares the different production units in a single time period, the productivity growth represents the degree of the productivity change in two different time periods. In

this study, the productivity growth is derived from four directional distance functions in the two time periods, p and p+1. Here, we divide the productivities into the individual productivity change based on the individual frontier, and the meta-productivity change based on the meta-frontier, and the productivity gap between the two productivities. By happenstance, the annual meta-productivity changes of both countries on average are the same as the productivity changes within each country's frontier itself. The individual productivity and the meta-productivity of Korea showed 1.086 on average, respectively. That is, the annual average growth of Korea is 8.6 percent. . On the other hand, the individual productivity and the meta-productivity of China are 0.966 on average, respectively. That is, China showed an annual productivity decline of 3.4 percent on average growth, meaning that while the manufacturing industries in Korea have contributed to the rapid extension of the frontier annually, those of China have not.

Taking a closer look at each individual industry, the types of manufacturing industries of Korea such as basic metal(1.150), processing of recycled materials, (1.143), chemicals and chemical products(1.118), audio-visual equipment(1.108), motor vehicles (1.103), wearing apparel and fur products(1.095) and other transport equipment(1.090) in descending order, showed productivity improvement, all higher than the average. These were the same types of industries when it comes to both individual productivity and meta-productivity. However, the meta-productivity growth is relatively lower than the individual productivity growth in the cases of publishing, printing & recorded media, and fabricated metal products, and other electric machinery. On the contrary, the individual productivity growth is relatively higher than the meta-productivity growth in the cases of manufacture of rubber and plastics, manufacture of other machinery and equipment, medical and precision, and furniture and other manufacturing. On the other hand, nearly half of manufacturing industries in China such as chemical fiber, chemicals and chemical products, refining and rolling of metal, publishing, printing & recorded media, and coke, refined, petroleum products and nuclear fuel are higher than the average in terms of the individual productivity. Among them, chemical fiber(1.100), chemicals and chemical products(1.068), refining and rolling of metal(1.048), publishing, printing & recorded media(1.015), coke, refined, petroleum products(1.010), non-metallic mineral products(1.003), and so on, showed improvement in terms of the productivity growth.

However, in the case of China, the meta-productivity indexes of just a few types of industries such as food products and beverages, tobacco, and chemicals and chemical products, and non-metallic mineral products are higher than the individual productivity indexes. That is, the meta-productivity is relatively low compared to the individual productivity growth in most types of industry such as chemical fiber, coke, refined & petroleum products, medical and precision, manufacture of plastics, and metal products, and manufacture of other machinery and equipment. Therefore, the Korean manufacturing industries show productivity improvement at an annual rate of 8.6 percent while the Chinese manufacturing industries show productivity decline at an annual rate of 3.4 percent in terms of the productivity excluding the environmental element. Each individual frontier and each meta-frontier in both countries are almost identical as shown by the productivity gap of 1.000 in terms of the productivity gap of each country.

The individual technical efficiency, the meta-technical efficiency, and the technology gap, when considering the environmental factor, are shown in <Table 3>. The individual technical efficiency of China (0.903) is higher than that of Korea (0.726), even in terms of the technical efficiency including the environmental factor. In the case of Korea, tobacco, and coke, refined, petroleum products & nuclear fuel showed also the maximum efficiency of 1.000 as when comparing the technical efficiency including the environmental factor. Wearing apparel and fur products (0.859), leather, luggage and harness (0.824), audio-visual equipment (0.775), and motor vehicles (0.766) are more efficient in descending order, than the average. In China, food products and beverages, tobacco, leather and fur manufacturing, coke, refined, petroleum products & nuclear fuel, manufacture of plastics, non-metal products, and machinery, equipment & electric machinery showed the maximum efficiency in descending order. Metal products (0.965) and publishing, printing, & recorded media (0.921) are more efficient than the average. China (0.874) is higher than Korea (0.724), even in terms of the meta-technical efficiencies considering the environmental element. When it comes to meta-technical efficiency, in the case of Korea, tobacco, and coke, refined, petroleum products & nuclear fuel showed also the maximum efficiency, which are the same as the individual technical efficiencies. Wearing apparel and fur products (0.858), leather, luggage and harness (0.815), audio-visual equipment (0.775), and motor vehicles (0.766) are more efficient than the average (0.724).

In the case of China, coke, refined, petroleum products & nuclear fuel (0.978), metal products (0.956), food products and beverages & tobacco (0.929), and manufacture of plastics (0.919) are more efficient than the average (0.874), whereas leather and fur manufacturing and non-metal products, and machinery, equipment & electric machinery showed the maximum efficiency.

Comparing the technical efficiencies of both countries' manufacturing industries based on the meta-frontier, most of the manufacturing industries in China has an advantage when the environmental factor is excluded. However, Korea still has an advantage for coke, refined, petroleum products & nuclear fuel and chemicals and chemical products. The technical efficiency of the industries such as wearing apparel and fur articles, and leather, luggage and harness, and motor vehicles, including the environmental factor, showed higher improvement than the technical efficiency excluding the environmental factor.

<Table 2> the productivity and productivity gap excluding pollution (2000-2004 year)

Types of Industries		Meta	Inv.	MG
Korea	Food Products and Beverages	1.045	1.045	1.000
	Tobacco	0.968	0.968	1.000
	Textiles	1.038	1.038	1.000
	Wearing Apparel and Fur Articles	1.103	1.095	1.007
	Leather, Luggage and Harness	1.035	1.028	1.007
	Wood and Wood Products	1.055	1.055	1.000
	Pulp, Paper and Paper Products	1.038	1.038	1.000
	Publishing, Printing, and Recorded Media	1.023	1.025	0.998
	Coke, refined, Petroleum Products and Nuclear Fuel	1.085	1.085	1.000
	Chemicals and Chemical Products	1.118	1.118	1.000
	Manufacture of Rubber and Plastics	1.048	1.043	1.005
	Non-metallic Mineral Products	1.060	1.060	1.000
	Basic Metal	1.150	1.150	1.000
	Fabricated Metal Products	1.078	1.085	0.993
	Manufacture of Other Machinery and Equipment	1.078	1.075	1.002
	Other Electric Machinery	1.055	1.058	0.998

		Meta	Inv.	MG
	Audio-visual Equipment	1.108	1.108	1.000
	Medical and Precision	1.005	1.000	1.005
	Motor Vehicles	1.103	1.103	1.000
	Other Transport Equipment	1.090	1.090	1.000
	Furniture and Other Manufacturing.	1.075	1.070	1.005
	Processing of Recycled Materials	1.143	1.143	1.000
Average		1.086	1.086	1.000
China	Food Products and Beverages, Tobacco	0.975	0.965	1.010
	Textiles	0.980	0.985	0.995
	Leather and Fur Products	0.815	0.815	1.000
	Pulp, Paper and Products	0.975	0.975	1.000
	Publishing, Printing, and Recorded Media	1.010	1.015	0.995
	Coke, Refined, Petroleum Products and Nuclear Fuel	0.993	1.010	0.983
	Chemicals and Chemical Products	1.095	1.068	1.026
	Medical Products	0.960	0.968	0.992
	Chemical Fiber	1.075	1.100	0.977
	Manufacture of Rubber	0.988	0.988	1.000
	Manufacture of Plastics	0.940	0.943	0.997
	Non-metallic Mineral Products	0.925	0.923	1.003
	Refining and Rolling of Metal	1.048	1.048	1.000
	Refining and Rolling of Non-metal	0.993	1.003	0.990
	Metal Products	0.903	0.908	0.994
	Machinery and Equipment, Electric Machinery	0.850	0.855	0.994
Average		0.966	0.966	1.000

1) Meta and Inv. in this table mean meta-productivity and individual productivity, respectively while MG means productivity gap.
2) The average was estimated by giving a weighted value based on the output (added value).
3) The Productivity change index was estimated by giving a weighted value which was acquired as taking the geometric mean between the period, p and the period, p+1 since the productivity change index represents the productivity change during the two different periods.

<Table 3> the meta-technical efficiency and technology gap including pollution (2000-2004 year)

Types of Industries		Meta	Inv.	TG
Korea	Food Products and Beverages	0.677	0.680	0.996
	Tobacco	1.000	1.000	1.000
	Textiles	0.626	0.632	0.989

	Wearing Apparel and Fur Articles	0.858	0.859	0.999
	Leather, Luggage and Harness	0.815	0.824	0.988
	Wood and Wood Products	0.617	0.619	0.997
	Pulp, Paper and Paper Products	0.626	0.629	0.995
	Publishing, Printing, and Recorded Media	0.664	0.664	1.000
	Coke, Refined, Petroleum Products and Nuclear Fuel	1.000	1.000	1.000
	Chemicals and Chemical Products	0.678	0.678	1.000
	Manufacture of Rubber and Plastics	0.644	0.651	0.989
	Non-metallic Mineral Products	0.637	0.648	0.982
	Basic Metal	0.685	0.685	1.000
	Fabricated Metal Products	0.644	0.645	0.998
	Manufacture of Other Machinery and Equipment	0.685	0.685	1.000
	Other Electric Machinery	0.702	0.702	1.000
	Audio-visual Equipment	0.775	0.775	1.000
	Medical and Precision	0.710	0.710	1.000
	Motor Vehicles	0.766	0.766	1.000
	Other Transport Equipment	0.691	0.691	1.000
	Manu Furniture and Other Manufacturing	0.687	0.688	0.998
	Processing of Recycled Materials	0.670	0.670	0.999
Average		0.724	0.726	0.997
China	Food Products and Beverages, Tobacco	0.929	1.000	0.929
	Textiles	0.776	0.777	0.998
	Leather and Fur Products	1.000	1.000	1.000
	Pulp, Paper and Products	0.788	0.795	0.991
	Publishing, Printing, and Recorded Media	0.788	0.921	0.856
	Coke, Refined, Petroleum Products and Nuclear Fuel	0.978	1.000	0.978
	Chemicals and Chemical Products	0.631	0.723	0.873
	Medical Products	0.686	0.692	0.990
	Chemical Fiber	0.836	0.847	0.987
	Manufacture of Rubber	0.779	0.789	0.987
	Manufacture of Plastics	0.919	1.000	0.919
	Non-metallic Mineral Products	0.816	0.816	1.000
	Refining and Rolling of Metal	0.805	0.812	0.991
	Refining and Rolling of Non-metal	1.000	1.000	1.000
	Metal Products	0.956	0.965	0.991
	Machinery and Equipment, Electric Machinery	1.000	1.000	1.000
Average		0.874	0.903	0.968

1) Meta and Inv. in this table mean meta-technical efficiency and individual technical efficiency, respectively while TG means technology gap.

2) The average was measured by giving a weighted value based on the output (added value).

3) The technical efficiency is efficient if it is zero, however, we use its reciprocal in order to avoid confusing it with the value of productivity (the technical efficiency has the value from zero to one, and it shows being efficient if it is one in this table).

In the case of China, the technical efficiency of the industries such as non-metallic mineral products, and refining and rolling of metal, and refining and rolling of non-metal showed higher improvement than the technical efficiency excluding the environmental factor. When it comes to the technical gap, in the case of Korea, nearly half of the manufacturing industries including tobacco, and coke, refined, petroleum products & nuclear fuel, and chemicals and chemical products recorded high economic performance while, in the case of China, only a few types of industries such as leather and fur products, and refining and rolling of metal, and refining and rolling of non-metal, and machinery, equipment and electric machinery showed high economic performance. This indicates that the Korean manufacturing industries lie in the production condition of sustainable growth by individual industry although they show lower economic performance those in China, on average. When it comes to the meta-frontier, the technical efficiencies including the environmental element in Korea and China show improvement of 2.1 percent and 3.0 percent on average, respectively, compared to the general technical efficiencies.

Environmental regulations transform the resources to produce into the resources to decontaminate. That is, the technical efficiencies including the environmental factor become greater than the technical efficiencies excluding the environmental factor, as the production possibility curve shrinks when considering pollution abatement activities.

The meta-technical efficiencies including the environmental element of the manufacturing industries in both Korea and China represent a lower level than the individual technical efficiencies in both countries on average. However, the gap between the individual technical efficiency (0.726) and the meta-technical efficiency (0.724) in Korea is comparatively lower than the gap between the individual technical efficiency (0.903) and the meta-technical efficiency (0.874) in China. Consequently, the technology gap of Korean manufacturing shows 0.997, on average, and the technology gap of Chinese manufacturing shows 0.968, on average. Thus, it indicates that the frontier of the individual technical efficiency of the Korean manufacturing industries is closer to the meta-frontier that integrates Korea with China rather than the frontier of the individual technical efficiency of the Chinese manufacturing industries.

<Table 4> the productivity and productivity gap including pollution (2000-2004 year)

Types of Industries		Meta	Inv.	MLG
Korea	Food Products and Beverages	1.009	1.011	0.998
	Tobacco	1.012	1.006	1.006
	Textiles	1.006	1.007	0.999
	Wearing Apparel and Fur Articles	1.008	1.038	0.970
	Leather, Luggage and Harness	1.039	1.007	1.032
	Wood and Wood Products	1.009	1.010	0.999

	Pulp, Paper and Paper Products	1.010	1.007	1.004
	Publishing, Printing, and Recorded Media	1.007	1.005	1.003
	Coke, Refined, Petroleum Products and Nuclear Fuel	1.005	1.005	1.000
	Chemicals and Chemical Products	1.025	1.031	0.994
	Manufacture of Rubber and Plastics	1.031	1.010	1.021
	Non-metallic Mineral Products	1.010	1.009	1.002
	Basic Metal	1.014	1.048	0.967
	Fabricated Metal Products	1.048	1.019	1.028
	Manufacture of Other Machinery and Equipment	1.020	1.021	0.999
	Other Electric Machinery	0.998	1.017	0.982
	Audio-visual Equipment	1.015	1.032	0.984
	Medical and Precision	1.031	1.000	1.032
	Motor Vehicles	1.000	1.036	0.965
	Other Transport Equipment	1.036	1.048	0.988
	Furniture and Other Manufacturing	1.035	1.020	1.015
	Processing of Recycled Materials	1.020	1.042	0.979
Average		1.015	1.025	0.991
China	Food Products and Beverages, Tobacco	0.988	1.001	0.987
	Textiles	0.973	0.974	0.999
	Leather and Fur Products	0.989	0.990	0.999
	Pulp, Paper and Products	0.977	1.015	0.962
	Publishing, Printing, and Recorded Media	1.020	1.066	0.957
	Coke, Refined, Petroleum Products and Nuclear Fuel	1.009	0.991	1.018
	Chemicals and Chemical Products	1.018	1.014	1.004
	Medical Products	0.987	0.998	0.989
	Chemical Fiber	1.023	1.023	1.000
	Manufacture of Rubber	1.001	1.005	0.996
	Manufacture of Plastics	0.945	1.006	0.940
	Non-metallic Mineral Products	1.173	1.039	1.129
	Refining and Rolling of Metal	1.023	1.022	1.001
	Refining and Rolling of Non-metal	1.130	0.951	1.188
	Metal Products	0.997	1.029	0.969
	Machinery and Equipment, Electric Machinery	0.934	0.998	0.935
Average		0.991	1.002	0.989

1) Meta and Inv. in this table mean meta-productivity and individual productivity, respectively while MLG means productivity gap.

2) The average was estimated by giving a weighted value based on the output (added value).

3) The Productivity change index was estimated by giving a weighted value which was acquired as taking the geometric mean between the period, p and the period, p+1 since the productivity change index represents the productivity change during the two different periods.

<Table 4> shows the productivity change and the productivity gap of the manufacturing industries considering the environmental factor. Based on the individual productivity change and the meta-productivity change, Korea shows an annual average growth of 2.5 percent (1.025) and 1.5 percent (1.015), respectively. This is a lower level relatively compared to the case of ignoring the environmental element (1.086).

While China shows an annual average growth of 0.2 percent (1.002) in terms of the individual productivity, it shows an annual average decline of 0.9 percent (0.001) in terms of the meta-productivity. However, this value is higher compared to the case of excluding the environmental element. This also suggests that, whereas the manufacturing industries in Korea have contributed to the rapid extension of the frontier annually, those of China have not. Especially, based on the meta-productivity growth index, this means the degree of contribution is larger than one based on the individual productivity growth index. That is, the environmental productivity reflecting the pollution abatement activities of Korean manufacturing industries have increased significantly compared to the Chinese manufacturing industries for the same period. Based on the meta-frontier, the productivity growth of Chinese manufacturing industries including the environmental element, except for chemical fiber, chemicals and chemical products, and refining and rolling of metal has increased more than the case excluding the environmental element. This implies that China has made an effort to seek pollution abatement activities as well as economic growth simultaneously since 2000.[9]

Taking a closer look at this, nearly half of all types of manufacturing industries of Korea showed more productivity improvement than the average (1.015) based on the meta-productivity, including fabricated metal products(1.048), leather, luggage and harness(1.039), other transport equipment (1.036), furniture and other manufacturing (1.035), manufacture of rubber and plastics (1.031), medical and precision (1.031), chemicals and chemical products (1.025), processing of recycled materials (1.020), and so on. These industries make up nearly half of the Korean manufacturing industries.

On the other hand, the types of manufacturing industries of China showed productivity improvement based on the meta-productivity, such as non-metallic mineral products (1.173), refining and rolling of non-metal (1.130), chemical fiber (1.023), publishing, refining and rolling of metal (1.023), printing, and recorded media (1.020), coke, refined, petroleum products and nuclear fuel (1.009), and so on.

Consequently, while the types of manufacturing industries of China showed an annual average decline of 0.9 percent (0.991) in terms of the meta-productivity, the types of manufacturing industries of Korea showed an annual average growth of 1.5 percent in terms of the meta-productivity. Moreover, the technology gap of Korea showed 0.991, meaning it is slightly higher than that of China (0.989). That is, Korea is slightly higher than China in the case including the environmental element, compared to the case that shows 1.000, respectively, in terms of the general productivity change excluding the environmental element in both Korea and China.

The results of this study are similar to those of Myung-Hun Lee e*t al.* (2008). Even though they compared the Korean manufacturing industries with Chinese manufacturing industries based on the individual frontier, they insisted that the technical efficiency of the Korean manufacturing industries (0.74 on average) was lower than that of Chinese manufacturing industries on average. However, they did not compare the two countries based on the objective meat-frontier. Furthermore, in this study, Korea demonstrates an advantage in the manufacturing industries such as coke, refined, petroleum products and nuclear fuel, and chemicals and chemical products, and non-metallic mineral products, while most manufacturing

[9] The Chinese government has been interested in international environmental protection since the Earth Summit in 1992. The Chinese government started to conduct the maintenance and revision of the environmental laws and regulations after the year 2000, even though the Chinese government promoted the environmental laws and regulations gradually after the middle of 1990s.

industries in China have an advantage in terms of the meta-technical efficiency by individual industry. However, Myung-Hun Lee *et al*. showed that most of the Chinese manufacturing industries have an advantage except for the chemical and non-metallic mineral products. It seems that there are differences in analysis periods and approaches in terms of the non-parametric meta-frontier and the parametric individual frontier.

IV. CONCLUSION

In this study we empirically examined the individual technical efficiencies, the meta-technical efficiencies, and the productivity change and the meta- productivity change for Korean manufacturing industries and Chinese manufacturing industries, distinguishing the case including the environmental factor from that excluding the environmental factor. Generally, the Chinese manufacturing industries showed higher technical efficiencies than the Korean manufacturing industries in both the case of including the environmental element and in the case of excluding the environmental element. Overall, the Chinese manufacturing industries annually demonstrate high technical efficiencies in both the case considering the environmental element and that excluding the environmental element, compared to the Korean manufacturing industries. That is, for 2000-2004, based on the meta-technical efficiency ignoring the environmental factor, the Chinese manufacturing industries (0.844) represent a higher level of efficiency than the Korean manufacturing industries (0.703). It is hypothesized that this is the result of the Chinese manufacturing industries having been mainly dependant on foreign capital such as FDI (Foreign Direct Investment) since the middle of the 1980s, so that high technology and new equipment, made possible by investments of foreign capital. That is why the meta-technical efficiency of the Chinese manufacturing industries is greater than that of the Korean manufacturing industries. However, when it comes to the technology gap, China and Korea represent 0.960 and 0.974, respectively, on average. This indicates that the frontier of the individual technical efficiency of Korean manufacturing industries is closer to the meta-frontier that integrated Korea with China, rather than the frontier of the individual technical efficiency of China's manufacturing industries. Also, the meta-technical efficiencies, including the environmental element of the Chinese manufacturing industries (0.874), are higher than the Korean manufacturing industries (0.724). This implies that even reflecting the environmental factor cannot reverse the absolute advantage in production between the two countries. That is, even though the rigor of environmental regulations in Korea is relatively high, it is not enough to reverse the ranks of the technical efficiencies.

In addition, based on the meta-frontier, the technical efficiencies including the environmental element in both Korea and China show an improvement of 2.1 percent and 3.0 percent on average, respectively, compared to the general technical efficiencies. This is probably because environmental regulations transform the resources to produce into the resources to decontaminate, so that the technical efficiencies including the environmental factor become greater than those excluding the environmental facto as the production possibility curve shrinks as pollution abatement activities are considered.

Whereas, based on the general productivity, Korea represents an annual average growth of 8.6 percent by showing the individual and meta-productivities as 1.086, China demonstrates an annual average decline of 3.4 percent by showing the individual and meta-productivities at 0.966, meaning that while the manufacturing industries in Korea have contributed to the rapid extension of the frontier annually, those of China have not. The productivity gaps in China and Korea showed 1.000, respectively. Based on the environmental productivity, the individual productivity and the meta-productivity of Korea represent 1.025 and 1.015, respectively.

In China, while the individual productivity (1.002) shows an annual average growth of 0.2 percent, the meta-productivity (0.991) shows an annual average decline of 0.9 percent. This means when it comes to the environmental productivity considering pollution abatement activities, the productivity of the Korean manufacturing industries increased more than that of the Chinese manufacturing industries during the same period. Therefore, the Chinese manufacturing industries are in a difficult production condition to increase the outputs and implement pollution abatement activities simultaneously. This implies that the Korean manufacturing industries are relatively closer to sustainable growth than are the Chinese manufacturing industries.

By applying the meta-frontier, we discovered that there exists a difference between the technical efficiency depending on the individual frontier and that depending on the meta-frontier. Especially, the meta-frontier technical efficiency is lower. In addition, the meta-productivity changes reflecting the environmental factor are lower in both countries, compared to the individual productivity changes, however, the meta-productivity changes of China decreased more than those of Korea. It means that there is a possibility to distort reality, when estimating technical efficiencies and the productivity changes by using the existing frontier.

Consequently, based on the meta-productivity, heavy and chemicals industry has an advantage in the Korean manufacturing industries such as the coke, refined, petroleum products and nuclear fuel manufacturing industry, chemicals and chemical products have an advantage, while the rest of the Chinese manufacturing industries have an advantage, except for the tobacco industry. Fortunately, the increasing speed of productivity in Korea is somewhat higher and that in China, as the meta-productivities of the Korean manufacturing industries show higher than those of manufacturing industries, regardless of the environmental factor.

As we have seen in the empirical results, according to the emergence of China, we should make an effort of specializing in the businesses that have an advantage, and the technical innovation through adopting new technology which can be replace with the old machinery, in order to promote the productivity and the efficiency in the Korean manufacturing industries. Furthermore, the innovation should be done over machinery, technology, training the skilled, the change of the system of process of production, institutions of business administration.

Although the advantage in the Chinese manufacturing industries will give a wake-up call to the Korean manufacturing industries, there might be a possibility to offset the situation because of the increase cost if the environmental regulations are strengthened in the Chinese manufacturing industries due to international environmental regulations. However, the influence is not significant as we can see the technical efficiencies. In order to be less influenced by the effect of the Chinese manufacturing industries, the important thing is that the Korean manufacturing industries need to differentiate themselves from the Chinese manufacturing industries, by seeking high quality through technical innovation, and specializing in the areas of high technology such as medical and precision, audio-visual, motor vehicles, and machinery and equipment and electrical machinery. These specializations in the manufacturing industries should be accomplished by harmonization with the entire Korean industrial structure.

The principle limitation of this study is that we were unable to compare precisely and for longer time periods since the proper classifications of industries and the complete data of pollution in China were not available to us. This will be a task we will address in the future.

REFERENCES

Afriat, S. N., 1970, “Efficiency Estimation of Production Function”, *International Economic Review,* Vol. 13(3), pp.568-598.

Banker, R. D., A. Charnes, and W. Cooper, 1984, “Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis”, *Management Science*, Vol. 30(9), pp.1078-1092.

Battese, G. E. and D. S. P. Rao., 2002, “Technology Gap, Efficiency, and a Stochastic Meta-frontier Function”, *International Journal of Business and Economics*1, Vol. 1 (2), pp. 87-93.

Battese, G. E. and Rao, D. S. P., and C. J. O'Donnell., 2004, "A Meta-frontier Production Function for Estimation of Technical Efficiencies and Technology Gaps for Firms Operating Under Different Technologies", *Journal of Productivity Analysis,* Vol. 21(1), pp. 91-103.

Battese, G. E., 2008, "Meta-frontier frameworks for the study of firm-level efficiencies and technology ratios", *Empirical Economics,* Vol. 34(2), pp. 231-255.

Caves, D. W., Christensen, L. R., and Diewert, E., 1982, "Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity", *Econometrica,* Vol. 50 (6), pp. 1393-1413.

Chen K. H., Huang Y. J., and Yang C. H., 2009, "Analysis of Regional Productivity Growth in China: A Generalized Meta-frontier MPI Approach", *China Economic Review,* Vol. 20(4), pp777-792.

Chung Y. H., Färe, R., and S. Grosskopf, 1997, "Productivity and Undesirable Output: A Directional Distance Function Approach", *Journal of Environmental Management,* Vol. 51(3), pp. 229-240.

Coelli, Tim, D. S. Prasada Rao & George E. Battese, 1998, *An Introduction to Efficiency and Productivity Analysis,* Boston: Kluwer Academic Publishers.

Domazlicky, B. and W. Weber, 2004, "Does Environmental Protection Lead to Slower Productivity Growth in the Chemical Industry," *Environmental and Resource Economics,* Vol. 28(3), pp.301-324.

Färe, R., Grosskopf, S., and C. Pasurka, 2001, "Accounting for Air Pollution Emissions in Measures of State Manufacturing Productivity Growth", *Journal of Regional Science,* Vol. 4(3), pp.81-409.

Färe, R., Grosskopf, S., Norris, M., and Z. Zhang., 1994, "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries", *The American Economic Review,* Vol. 84(1), pp. 66-83.

Farrell, M. J., 1957, "The Measurement of Productive Efficiency", *Journal of Royal Statistical Society ,* Vol. 20(3), pp.253-282.

Hailu Atakelty, and T. S. Veeman, 2000, "Environmentally Sensitive Productivity Analysis of the Canadian Pulp and Paper Industry, 1959-1994: An Input Distance Function Approach", *Journal of Environmental Economics and Management,* Vol. 40(3), pp.189-210.

Jemaa, M. M. B. and M. A. Dhif., 2005, "Agricultural Productivity and Technological Gap between MENA Region and Some European Countries: A Meta-frontier Approach", Economic Research Forum, pp.1-20.

Myung-Hun Lee, 2007, "A study on Porter Hypothesis: A Distance Function Approach", *Environmental and Resource Economics Review*, Vol. 16(1), pp.171-197.

Rungsuriyawiboon, S., 2008, "Recent Evidence on Agricultural Efficiency and China: A Meta frontier Approach," Asian-Pacific Productivity Conference.

Shaik, S. and R. K. Perrin., 2001, "Agricultural Productivity and Environmental Impacts: The Role of Non-parametric Analysis," American Agricultural Economics Association Meetings, August 5-8, Chicago, IL.

Sang-Mok Kang, and Moon-Hwee., 2009, "Analysis of Regional Environment Productivity in China", *Journal of the Economic Geographical Society of Korea*, Vol. 12(2), pp. 215-233.

Sang-Mok Kang, and Sang-kyu Jo., 2009, "Technical efficiency and Technical Gap of Strategic Industries of Busan Using Meta-frontier", *Korean Association of Regional Studies,* Vol. 17, pp.49-73.

Sang-Mok Kang, and Seong-Min Yoon., 2008, "Environmentally-adjusted Productivity Growth and Growth Accounting Analysis in Korean and Chinese Manufacturing", *The Northeast Asia Economic Association of Korea,* Vol. 20(3), pp.155-191.

Zaim, O. and F. Taskin., 2000, "Environmental Efficiency in Carbon Dioxide Emissions in the OECD: A Nonparametric Approach", *Journal of Environmental Management* 58(2), pp.95-107.

http://www.ft.com/cms

Environmental Tax, Commitment, and Innovations on Process and Environmental R&D

Shih-Jye Wu*

Department of Political Economy, National Sun Yat-Sen University, Taiwan

Tsung-Hsiu Tsai

Department of Applied Economics, National University of Kaohsiung, Taiwan

ABSTRACT

In this paper, we investigate how a monopolist's innovation decisions on both process and environmental R&D are affected by the government's credibility. It is found that when the government cannot pre-commit to an environmental tax, the monopolist's output and the amount of process R&D is higher while its abatement level and its amount of environmental R&D is lower, than the ones where the government can pre-commit to the tax. The equilibrium tax rate under the non-commitment case is lower than the one where the government can pre-commit. These results imply that if the marginal damage is very high, the government may want to pre-commit to the environmental tax.

Keywords: commitment, environmental tax, process innovation, environmental innovation

* Corresponding author, Department of Political Economy, National Sun Yat-Sen University , 70, Lien-hai Road, Kaohsiung 804, Taiwan. Email: shihjye@faculty.nsysu.edu.tw Tel: 886-7-5252000,ext5588. Fax: 886-7-5919319.

1. Introduction

The purpose of environmental regulation is to correct environmental externality generated by firms. Traditional wisdom believes that a government's regulation may increase a firm's cost burden and reduce its competition. Ever since the famous Porter Hypothesis stimulation in the 1990s however, scholars start to recognize that the benefits of environmental regulation should also take into account the dynamic benefit of environmental innovation induced by the government's regulation (Regulate, 2005).

Following this reorganization, a nature move is to ask what kind of government regulation can provide more incentive for firms to undertake R&D (Regulate, 2005; Montero, 2002).[1] Among this line of literature, some scholars bring up the government's credibility problem (Petrakis and Xepapadeas, 1999; Kennedy and Laplante, 1999; Amacher and Malik, 2002; Requate and Unold, 2003). As an R&D innovation investment is a long-term decision and the government's legislative procedures are often inflexible, it is very possible that the government may not be able to pre-commit a specific regulatory measure to firms. This kind of governmental credibility problem may affect on firms' incentives to undertake R&D.

In this paper, we follow the stream of the literature that discusses the influence of credibility on firms' incentives on R&D. We however, expand the literature and generalize firms' R&D decisions by taking both environmental and traditional process R&D into

[1] Reguate (2005) has provided an excellent review in the ranking of environmental regulation on R&D incentives.

consideration. In this regard, we basically extend the research question raised by Petrakis and Xepapadeas (1999) in which they compare a monopolist's environmental innovation efforts when the government can or cannot commit on an environmental tax. Different from their work however, we take into account two types of R&D in firms' decision-making.

Incorporating two kinds of R&D in firms' R&D decisions is pioneered by Ulph and Ulph (1996). They have pointed correctly that if environmental regulation is little or absence, firms would have no incentive to undertake environmental R&D to reduce their emission levels. In this case, they may go for the traditional type of process R&D to lower production costs. Once the government imposes an environmental regulation, firms would naturally have incentives to undertake both types of R&D. The amounts of both environmental R&D and process R&D undertaken by firms will be affected by the government's regulation.

Our work however is also different from Ulph and Ulph's. They consider the firms' two R&D decisions in a trade framework; we limit our analysis in a closed economy in which the domestic consumers are also affected by the results of R&D. Moreover, Ulph and Ulph do not consider the government's credibility problem but we do. Our focus is to compare the firms' outputs, the amounts of process R&D and environmental R&D to undertake, and the levels of environmental tax when the government can or cannot commit on an emission tax.

Two three-stage models are built to represent the interactions between a monopoly and the government. In the case whether the government can commit on an environmental tax, the government will determine an optimal environmental tax in the first stage. In the second stage, the monopolist chooses its optimal amount on two types of R&D. In the third stage, the firm determines its output. In the case where the government cannot commit on the environmental tax, the above first and the second stages of the model will be reversed while the third stage remains the same.

It is found that when the government cannot pre-commit to an environmental tax, the monopolist's amount of process R&D is higher and its amount of environmental R&D is lower than the levels where the government can pre-commit. Moreover, the equilibrium tax rate under the non-commitment case is lower than the one where the government can pre-commit. As a result, the monopolist's output is higher but its amount of abatement is lower, than the levels where the government is credible on the tax.

The rest of this paper is organized as follows. Section 2 introduces the model setting. In section 3 and 4, we examine the scenarios when the government can or cannot commit on the environmental tax, respectively. Section 5 compares the results. Finally, section 6 concludes.

2. The Model

We consider a monopolist that produces homogenous good in the market. The inverse market demand function for the good is $p = a - Q$, where p is the market price, a is the market size, and Q is the quantity demanded. The firm's production causes pollution. To internalize this externality, the government imposes an environmental tax on the firm's emission. Denote t as the environmental tax per unit of emission. Without loss of generality, we assume each output generates one unit of emission. Denote a as the firm's emission abatement level. The firm's environmental tax payment thus is $tE = t(Q - a)$ where E is the total emission with $E = (Q - a)$. The total environmental damage caused by the firm is $d(Q - a)$ where d is the marginal environmental damage per unit of emission.

Assume that the firm now is considering an R&D investment to improve its efficiency. There are two available types of R&D that the firm can adopt: process R&D and environmental R&D. The process R&D can reduce the firm's production cost; while the environmental R&D can reduce the firm's environmental tax burden. Denote the amounts of process and environmental R&D that the firm undertakes as x and z respectively. The firm's R&D expenditure is assumed as $F(x, z) = \gamma(x^2 + z^2)/2$, where γ represents the degree of decreasing returns to scale for both types of R&D efforts, with γ>1.

Let $\bar{c}$ be the firm's initial marginal production cost. After undertaking process R&D, the firm's total production cost will become $(\bar{c} - x)Q$. Similarly, let the firm's initial abatement cost be $a^2/2$. After undertaking environmental R&D, its abatement cost becomes $a^2/2(1 + z)$. The firm's marginal abatement cost is thus equal to $a/(1 + z)$ which is decreasing with z. Note that in order to minimize its abatement cost, the firm will set its abatement at the level where the marginal abatement cost equals to the environmental tax, i.e. $t = a/(1+z)$. This implies that the firm's cost-minimizing abatement level is a function of t, i.e. $a = t(1+z)$. We can thus rewrite the firm's abatement cost as $a^2/2(1+z) = t^2(1+z)/2$.

Overall, the firm's cost function includes the production cost, the environmental tax payment, the abatement cost, and the R&D expenditure. We write it as follows:

$$\begin{aligned} TC(t,x,z) &= (\bar{c}-x)Q + t(Q-a) + \frac{a^2}{2(1+z)} + \frac{\gamma(x^2+z^2)}{2} \\ &= (\bar{c}-x)Q + tQ - \frac{t^2(1+z)}{2} + \frac{\gamma(x^2+z^2)}{2} \end{aligned} \tag{1}$$

The Benchmark

Based on the above setting, we can examine the first-best outcome as a benchmark model. Suppose that the government can choose the firm's output, the amounts of process and environmental R&D to maximize the social welfare function which is represented as next:

$$\int_0^Q p(s)ds - (\bar{c}-x)Q - \frac{a^2}{2(1+z)} - \frac{\gamma(x^2+z^2)}{2} - d(Q-a) \tag{2}$$

The social welfare contains the consumer surplus, the monopolist's profit and the negative environmental damage. Given the levels of x and z, we solve the social optimal output and amount of abatement first, denoted them as $\hat{Q}$ and $\hat{a}$ respectively. Differentiating equation (2) with respect to Q and a, we can calculate $\hat{Q}$ and $\hat{a}$ as next:

$$\hat{Q} = s + x - d \tag{3}$$

$$\hat{a} = (1+z)d \tag{4}$$

where we make $s = a - \overline{c}$ and $s > d$.

Substituting $\hat{Q}$ and $\hat{a}$ into the social welfare function and differentiating it with respect to *x* and *z*, we can obtain the two first-order conditions for the social optimal amounts of process and environmental R&D ($\hat{x}, \hat{z}$):

$$\frac{dW}{dx} = \hat{Q} - \gamma\hat{x} = 0 \tag{5}$$

$$\frac{dW}{dz} = \frac{\hat{a}^2}{2(1+\hat{z})^2} - \gamma\hat{z} = 0 \tag{6}$$

Solving (5) and (6) simultaneously, and together with (3) and (4), we can obtain the social optimal output, the amount of abatement, and the amounts of two types of R&D as next:

$$\hat{Q} = \frac{\gamma(s-d)}{\gamma-1}, \quad \hat{a} = (1+\frac{d^2}{2\gamma})d, \quad \hat{x} = \frac{s-d}{\gamma-1}, \text{ and } \hat{z} = \frac{d^2}{2\gamma} \tag{7}$$

As $s > d$ and $\gamma>1$ hold, the above values are all positive.

3. Pre-commitment on Environmental Tax

In this section, we examine the monopolist's output and its amounts of efforts on the two types of R&D when the government can pre-commit on the environmental tax. All of the outcomes in this section have an asterisk superscript to classify. As illustrated, there are three stages in this model. We look at the output stage first.

Output stage

The firm's profit function is the total revenue deducts the total cost illustrated in (1), which is represented as next:

$$\underset{Q}{Max} \quad [p(Q)-(\overline{c}-x)-t]Q+\frac{t^2(1+z)}{2}-\frac{\gamma(x^2+z^2)}{2} \tag{8}$$

From the first-order condition of (8), we can solve the firm's optimal output as:

$$Q^*=\frac{s+x-t}{2} \tag{9}$$

Note that the optimal output increases with the process R&D only but decreases with the tax. This is because the process R&D reduces the firm's marginal production cost while the tax increases the firm's cost burden. Their impacts on the output are thus evidently. One can discover however, the optimal output is not affected by the environmental R&D at all. This is because the result of environmental R&D mainly affects on the firm's abatement decision but not on the output decision.

<u>R&D stage</u>

Substituting Q^* into the firm's profit function and taking a derivative with respect to *x* and *z*, we can obtain two first-order conditions for the firm's optimal amounts of R&D efforts:

$$\frac{d\pi^*}{dx}=Q^*-\gamma x=0 \tag{10}$$

$$\frac{d\pi^*}{dz}=\frac{t^2}{2}-\gamma z=0 \tag{11}$$

Solving the above two equations simultaneously, we can obtain the optimal output, the abatement, and the amounts of R&D efforts as follows.

$$Q^*=\frac{\gamma(s-t)}{2\gamma-1},\quad a^*=t(1+\frac{t^2}{2\gamma}),\quad x^*=\frac{s-t}{2\gamma-1}\ \text{ and }\ z^*=\frac{t^2}{2\gamma} \tag{12}$$

One can easily observe that if the government can pre-commit on the environmental tax, the firm's optimal output decreases but its optimal abatement increases with the environmental tax, i.e. $dQ/dt < 0$ and $da/dt > 0$. Moreover, the firm's optimal process R&D effort *x* decreases with *t* while its optimal effort on the environmental R&D increases with *t*.

$$\frac{dx^*}{dt} = \frac{-1}{2\gamma - 1} < 0 \quad \text{and} \quad \frac{dz^*}{dt} = \frac{t}{2\gamma} > 0 \tag{13}$$

Proposition 1: If the government can pre-commit an environmental tax, then the increase of environmental tax would discourage the monopolist to undertake process R&D but would encourage it to adopt more environmental R&D.

The intuition of Proposition 1 is as follows. When the environmental tax increases, the firm will definitely do more abatement to save the tax burden. At this moment, if the firm undertakes environmental R&D, its marginal abatement cost can be reduced, which saves more on abatement expenditure. This is why the firm's environmental R&D increases with the environmental tax. On the other hand, the increase of environmental tax reduces the firm's output. The firm thus has less incentive to undertake process R&D.

<u>Tax Stage</u>

Next, we discuss how the government determines the pre-committed environmental tax. As defined before, the social welfare function includes the consumer surplus, the firm's profit, the tax revenue, and the negative environmental damage caused by emission.

$$W(t) = CS^* + \pi^* + (t-d)[Q^* - a^*]$$
$$= \frac{Q^{*2}}{2} + [Q^{*2} + \frac{(1+z^*)t^2}{2} - \frac{\gamma(x^{*2}+z^{*2})}{2}] + (t-d)(Q^{*2} - t(1+z^*)) \quad (14)$$

Substituting (12) into (14), we can obtain the first-order condition for the optimal environmental tax as follows:[2]

$$\frac{dW}{dt} = -\frac{\gamma^2(s-t)}{(2\gamma-1)^2} - (t-d)(1+\frac{3t^2}{2\gamma}+\frac{\gamma}{2\gamma-1}) = 0 \quad (15)$$

Note that evaluating the optimal tax at the Pigouvian level in which the tax equals the marginal damage, we find $\left.\frac{dW}{dt}\right|_{t^*=d} = -\frac{\gamma^2(s-t)}{(2\gamma-1)^2} < 0$. Therefore, we can tell that the optimal environmental tax is less than the marginal damage, i.e. $t^* < d$. Applying this result, one can easily observe that $a^* < \hat{a}$ and $z^* < \hat{z}$ when comparing the results of (12) with (7).

Proposition 2: If the government can pre-commit on an environmental tax, then the firm's abatement and amount of environmental R&D are both less than the levels in the social optimum. Nevertheless, the firm's output and amount of process R&D may be greater or less than the ones in the social optimum.

The intuition of proposition 2 is as follows. As the market is imperfect, the government has to set a lower environmental tax to compromise on the monopolist's already-low output. Due to $t^* < d$, the monopolist thus has less incentive to do abatement and environmental R&D when comparing with the social optimum.

The lower than marginal environmental damage environmental tax supposedly would have to increase the firm's output and the amount of process R&D. However, undertaking

[2] The stabilization condition $d^2W/dt^2 < 0$ is satisfied.

R&D is not costless. The firm thus has to balance between the pros and cons of investing in process R&D. Therefore, compared with the social optimum, the firm's output and the mount of process R&D effort are not certain.

4. Non-commitment Environmental Tax

In this section, we discuss the case where the government cannot pre-commit on the environmental tax. The firm decides its R&D decision before the government announces the level of environmental tax. We also intend to examine the firm's output, amount of abatement and its efforts on both types of R&D. We add a double asterisk on the superscript to classify the outcomes in this section.

Output stage

As the third stage of the game is the same for both commitment and non-commitment cases, we know that the monopolist's output under non-commitment is also:

$$Q^{**} = \frac{s+x-t}{2} \tag{16}$$

Tax stage

Next, we discuss the government's decision on the environmental tax. Substituting (16) into the social welfare function, which is represented next:

$$\begin{aligned} W(t) &= CS^{**} + \pi^{**} + (t-d)[Q^{**} - a] \\ &= \frac{Q^{**2}}{2} + [Q^{**2} + \frac{(1+z)t^2}{2} - \frac{\gamma(x^2+z^2)}{2}] + (t-d)(Q^{**2} - t(1+z)) \end{aligned} \tag{17}$$

The first-order condition of (17) is:

$$\frac{dW}{dt} = -\frac{Q^{**}}{2} - (t-d)(z+\frac{3}{2}) = 0$$

Therefore, the optimal tax, denoted as t^{**}, can be calculated as next:

$$t^{**} = d - \frac{Q^{**}}{3+2z} = \frac{-(s+x)+2(3+2z)d}{5+4z} \tag{18}$$

It is easy to tell from (18) regarding to the impacts of R&D efforts on the environmental tax:

$$\frac{dt^{**}}{dx} = \frac{-1}{5+4z} < 0 \text{ and } \frac{dt^{**}}{dz} = \frac{4(s+x-d)}{(5+4z)^2} > 0 \tag{19}$$

Proposition 3: If the monopolist's R&D decision moves first, then the government's environmental tax will decrease with the firm's process R&D and increase with its environmental R&D effort.

Proposition 3 is a very interesting result. The intuition is as follows. Since the firm's R&D decision moves first, the government cannot influence its incentive of R&D investment. Nevertheless, the government can exaggerate the impact of the firm's R&D efforts on the social welfare. First of all, according to (16), we know that the firm's process R&D effort can increase its output. From the social welfare point of view, the government may want to encourage the firm to produce more in order to exaggerate its process R&D impact on the social welfare. Therefore, the government has to lower the tax. This explains why the firm's process R&D reduces the government's tax.

Secondly, recall that we have illustrated the firm's abatement expenditure function as $a^2/2(1+z) = t^2(1+z)/2$. More environmental R&D effort can save the firm's expense on abatement. To exaggerate the firm's benefit on environmental R&D, the government can increase the tax. Moreover, the increase of the tax stimulates the firm to abate emission in a higher level, which reduces the total emission of the environment. Therefore, we see the government's environmental tax decision increases with the firm's environmental R&D effort.

Note that the results of proposition 3 is different from the ones derived in Petrakis and Xepapadeas (1999) in which they claimed that a monopolist's environmental R&D decreases with the environmental tax when the government has a non-credible problem. The difference between ours and theirs may be due to the model setting. Their environmental R&D is defined as the marginal emission reduction per unit of output while our environmental R&D affects on the firm's abatement decision only.

<u>R&D Stage</u>

Next, let us analyze the firm's decision on both types of R&D. Substituting (18) into the firm's profit function which is represented next:

$$\underset{x,z}{Max} \quad [a-Q^{**}-(\bar{c}-x)-t^{**}]Q^{**}+\frac{t^{**2}(1+z)}{2}-\frac{\gamma(x^2+z^2)}{2} \tag{20}$$

The firm's optimal amounts of R&D, denoted as x^{**}, z^{**} respectively, can be obtained from the two following first-order conditions:

$$\frac{d\pi^{*}}{dx}=Q^{**}-\gamma x^{**}-[Q^{**}-(1+z^{**})t^{**}]\frac{dt^{**}}{dx}=0 \tag{21}$$

$$\frac{d\pi^{**}}{dz}=\frac{t^{**2}}{2}-\gamma z^{**}-[Q^{**}-(1+z^{**})t^{**}]\frac{dt^{**}}{dz}=0 \tag{22}$$

The exact solutions of x^{**}, z^{**} are hard to calculated. However, when we evaluate (21) and (22) at the pre-commitment case (x^*, z^*, t^*), we find:

$$\left.\frac{d\pi^{**}}{dx}\right|_{(x^*,z^*,t^*)} = Q^* - \gamma x^* - [Q^* - (1+z^*)t^*]\frac{dt}{dx} > 0 \tag{23}$$

$$\left.\frac{d\pi^{**}}{dz}\right|_{x^*,z^*,t^*} = \frac{t^{*2}}{2} - \gamma z^* - [Q^* - (1+z^*)t^*]\frac{dt}{dz} < 0 \tag{24}$$

These imply that $x^{**} > x^*$ and $z^{**} < z^*$.

Proposition 4*: When the government cannot pre-commit to an environmental tax, the monopolist's amount of process R&D is higher and its amount of environmental R&D is lower than the levels where the government can pre-commit.*

The intuition of proposition 4 is as follows. From proposition 3 we have already learned that the governments environmental tax decreases (increases) with the firm's process R&D effort. In order to take advantage of the government's benevolence, the firm strategically would do more on process R&D but do less on environmental R&D.

Based on proposition 4, we can further conclude that the equilibrium tax rate under the non-commitment case is lower than the one when the government can pre-commit, due to the firm will invest more on process R&D to lower the government's tax rate. Consequently, under the non-commitment case, the firm's output is higher while its amount of abatement level is lower than the pre-commitment case, i.e. $t^{**} < t^*$.

Proposition 5*: The equilibrium tax rate under the non-commitment case is lower than the one where the government can pre-commit. As a result, the monopolist's output is higher but its amount of abatement is lower, than the levels where the government is credible on the tax.*

The proof of proposition 5 is evidently. As $Q=(s+x-t)/2$ and $a=t(1+z)$, the results of $x^{**}>x^{*}$, $z^{**}<z^{*}$, and $t^{**}<t^{*}$ will derive $Q^{**}>Q^{*}$ and $a^{**}<a^{*}$.

5. Conclusion

In this paper, we investigate how a monopolist's innovation decisions on both process and environmental R&D are affected by the government's credibility. By generalizing a firm's innovation decision, we are able to answer the question: should a government impose an environmental tax before or after a firm's R&D decision?

It is found that if the government is able to pre-commit on an environmental tax, the firm will undertake more environmental R&D. On the oppose case, the firm will adopt more on process R&D. These results imply that if the marginal damage is very high, the government may want to pre-commit to the environmental tax. If the marginal damage is small, then a non-committed environmental tax may induce the firm to adopt more process R&D. Therefore, it is ambiguous whether pre-commit can generate a higher social welfare level than the non-commitment case. The answer depends on the magnitude of environmental damage. As most literature concludes that pre-commitment can generate a higher level of social welfare, this result is an interesting and a new finding.

References:

Amacher, G.S., Malik, A.S., 2002. Pollution taxes when firms choose technologies. Southern Economic Journal 68 (4), 891-906.

Denicolo, V., 1999. Pollution-reducing innovations under taxes or permits. Oxford Economic Papers 51(1), 184-199.

Kennedy, P., Laplante, B., 1999. Environmental policy and time consistency: emission taxes and emissions trading. In: Petrakis, E., Sartzetakis, E.S., Xepapadeas, A. (Eds.), Environmental Regulation and Market Power: Competition, Time Consistency and International Trade. Edward Elgar, Cheltenham, U.K.

Petrakis, E., Xepapadeas, A., 1999. Does government precommitment promote environmental innovation? In: Petrakis, E., Sartzetakis, E.S., Xepapadeas, A. (Eds.), Environmental Regulation and Market Power: Competition, Time Consistency and International Trade. Edward Elgar, pp. 145-161.

Requate, T., Unold, W., 2003. Environmental policy incentives to adopt advanced abatement technology—will the true ranking please stand up? European Economic Review 47, 125-146.

Requate, T., 2005. Dynamic incentives by environmental policy instruments—a survey. Ecological Economics 54, 175-195.

Ulph, D., Ulph, A., 1996. Trade, strategic innovation and strategic environmental policy – a general analysis. In: Carraro C, Katsoulacos Y, Xepapadeas A. (Eds.), Environmental policy and market structure. Kluwer, pp. 181–208.

Endogenous R&D Model with Energy and Division of Capital Stock

Youngho Chang[1]

July 2010

Abstract

This study constructs an endogenous R&D model in which energy and capital are employed to produce the intermediate goods and the division of capital is assumed. Following the conventional endogenous R&D model, it incorporates energy use into the production of intermediate goods; meanwhile, capital is divided into two classes—one is invested in final goods sector directly, the other is allocated for the production of intermediate goods. With this modification, the study finds that the rising energy prices would spur the substitution of capital for intermediate goods in the final goods sector; such a substitution could alleviate the energy price shock. Contrasting with the existing literature, the present model finds that the growth rate of energy prices needs not to impede the rate of output growth. Rather the increasing energy price could spur innovations for energy technology, and then stimulate economic growth. It also finds that a tax aiming to energy conservation (e.g., a carbon tax) needs not to impede the economic growth; on the contrary, the tax could favor the economic growth if it is time-increasing and moderate. For the sake of energy conservation, the study suggests a policy that imposes a tax on energy use and subsidizes capital use.

Key words: Division of Capital Stock, Energy Use, Endogenous R&D Model, Induced Technological Change (ITC)

JEL Classifications: O33; Q32

---

[1] Division of Economics, Nanyang Technological University, HSS-04-65, 14 Nanyang Drive, Singapore 637332; Phone: +65-6513-8107; Fax: +65-6795-5797; Email: isyhchang@ntu.edu.sg

I. Introduction

Energy, or in a broader interpretation, natural resources have been added in the modern economic growth models. A Cobb-Douglas production function with resources, capital and labor as inputs was applied to produce final goods (Herfindahl and Kneese, 1974 and hereafter H-K model). The H-K model was extended by permitting the perfect substitution of physical capital for natural resources (Dasgupta and Heal, 1979 and hereafter D-H model). The D-H model shows that the substitution and technological progress overcome the problem of diminishing resources stock. However, these analyses have a drawback that they consider the technological progress as exogenous. In the 1990s, the endogenous R&D models address this concern by linking endogenous technological improvements with economic growth. Extending an endogenous R&D model (Romer, 1990), resources were introduced into the intermediate goods sector, but it is assumed that only resources are needed to produce intermediate goods (Aghion and Howitt, 1998). These models were modified further in such a way that both physical capital and energy are required for the production of intermediate goods (van Zon and Yetkiner, 2003). This study adopts the model by van Zon and Yetkiner (2003) and shows that the growth rate of energy prices stimulates the substitution of capital for energy in the intermediate goods sector.

Furthermore, this study modifies the endogenous R&D model (e.g., Romer, 1990) by introducing the idea of capital division (Davison, 1978). Even if most of the previous R&D models imply that the whole capital stock only presents in the intermediate goods sector, it is more realistic to suggest that capital goods might be used in both the production of intermediate goods and that of final goods. Therefore, the present model assumes that the total capital stock divides into two types of capital: one is used to exploit, extract raw energy, and then produce intermediate goods that provide composite energy services; the other is invested directly in final good production. With this modification, the present model finds that the rising energy prices spur the substitution of capital for intermediate goods in the final goods sector; such a substitution alleviates the energy price shock.

By linking energy use and the division of capital with an endogenous R&D model, this study aims to assert that the growth rate of energy prices may stimulate the rate of economic growth. The reason is that the rising energy prices spur the innovations and the substitution of capital for energy; if the partial output elasticity of energy is sufficient low, or the elasticity of substitution between consumption at any two points in time are sufficient large, the impact of energy price shock on economic growth is positive. Though the result contrasts with the existing studies focusing on energy prices and growth (e.g., van Zon and Yetkiner, 2003), it consists with the view of induced technological change (ITC).

The conventional view within the endogenous growth literature is that taxing interest income discourages economic growth and subsidizing investments promotes economic growth (e.g., Lucas, 1990; Rebelo, 1991; Jones et al., 1993; Barro and Sala-i-Martin, 1995; Stokey and Rebelo, 1995; Aghion and Howitt, 1998). This study gets the different result that some conditions have to be met to hold the common view.

It also indicates that, a tax that aims to energy conservation (e.g., a carbon tax) needs not to impede the economic growth; on the contrary, the tax may favor the economic growth if it is time-increasing and moderate. The reason lies in that such a tax works as an implement that accelerates the growth rate of energy price; consequently, it spurs innovations and output in the long run.

An endogenous R&D growth model (e.g., Romer, 1990) links endogenous technological progress with economic growth. It presents a three-sector economy: the R&D sector uses human capital to create new designs; the monopolistic intermediate goods sector buys the new designs and then combines the designs and raw capital to produce intermediate goods, it recovers the cost of purchasing the blueprints by selling intermediate goods at a price that is higher than its constant cost of production. The final goods sector manufactures a composite output with labor and intermediate goods as inputs.

The conventional endogenous model considers R&D sector the “growth engine” and finds that economic growth depends on the growth of innovations. It also derives a negative relation between the growth rate of output and the interest rate. The reason lies in that human capital allocated for R&D are compensated by the present value of the profits of intermediate goods; if the interest rate goes up, the present value of profits decreases, hence less human capital is attracted by the R&D sector. The result implies that an increase in the price of factor is harmful to the growth of output. This model contributes to the literature greatly by connecting human capital, expanding varieties and endogenous technology to economic growth. However, it does not consider the act of energy.

This study modifies an endogenous R&D growth model by treating energy as an input for intermediate goods. With the presence of energy, the production of intermediate goods can be interpreted as using capital to extract, exploit raw energy, and then supplying composite energy services. The monopolistic status of the intermediate sector not only comes from the new technologies it applies, but also comes from the privilege of energy. Therefore, the change of energy prices has impacts on innovations and economic growth. The present model assumes the intermediate goods are manufactured by a Cobb-Douglas function, which permits the elasticity of substitution of raw energy and capital to be unity. Though this assumption contrasts with the traditional literature (Dasgupta and Heal, 1974), it is supported by the energy technologies the R&D sector carries out. If the energy price increases, the firms alleviate the price shock by substituting capital for raw energy.

Another shortcoming in the conventional endogenous R&D model is it implies that the whole capital stock only presents in the intermediate goods production. This suggestion is unlikely consistent with the facts that a portion of capital acts as an input for final goods directly. Hence the present paper introduces the idea of capital division (Davison, 1978). It assumes that a proportion of capital combines raw energy to provide intermediate goods; other is invested in the final goods sector directly, in the form of machinery, etc. With this modification, the present model suggests that if the energy prices keep increasing, capital substitutes for raw energy in the intermediate goods sector; meanwhile in the final good sector, capital substitutes for intermediate goods. Therefore, the impact of energy price shock is alleviated.

The structure of this study is as follows. Section 2 reviews existing literature relating to endogenous growth models and technological change. Section 3 presents a modified model by including energy in the production of the intermediate goods and introducing the idea of capital division. In Section 4, this study suggests an energy conservation policy that imposes a time-increasing tax on energy consumption combining a constant capital subsidy rate, or a constant tax rate for energy use combining an increasing subsidy for capital use. The final section presents concluding remarks.

II. Endogenous Growth Model and Capital Stock

The concern of sustainability in modern economic framework can be traced back to the early 20th century. One of the most important contributes is the Hotelling rule (Hotelling, 1931), which links the depletion of natural resources with the market mechanism. Some neoclassical economists pay a lot attention to the role of resources in sustainable development. Their main point of view is that the manufactured capital and 'natural capital' (resources) build up the capital stock, and they are perfect substitutes. In the model developed by Herfindahl and Kneese (1974 and H-K model hereafter), the environment provides the natural resources needed by the economy and sucks up residuals of production. The H-K model also introduces resources into the Cobb-Douglas aggregate production function, combining manufactured capital and labor to produce the final goods. The result it gets is that the limited supply of resources causes the economy to shrink, unless the technological progress to improve the productivity of manufactured capital and labor and then counteract the negative impact of resources.

The H-K model is extended by Dasgupta and Heal (1979 and D-H model hereafter) by permitting the substitution of manufactured capital for exhaustible resources. The work of Dasgupta and Heal sets up the common suggestion of neoclassical economics that the problem of diminishing exhaustible resources can be overcome by the technological progress and the substitution of manufactured capital for resources. This is also the common view of neoclassical economics on resources. Adopting a Cobb-Douglas production function with capital, resources and labor as inputs, the D-H model shows that if the output elasticity of capital is greater than that of resources, the substitution offsets the problem posed by the depletion of exhaustible resources. The condition is satisfied because the empirical evidences shows that the productivity of capital is as about four times large as that of resources (Solow, 1974a; Hartwick, 1977; Dasgupta and Heal, 1979). As pointed out by Victor (1991), even though the conclusion Dasgupta and Heal get is too optimistic to be realistic, "it is nevertheless important for all those interested in sustainable development to consider the role of substitution in alleviating the pressures of a diminishing resource base." A few studies that employ a CES production function suggest that the elasticity of substitution between energy and other factors is no more than unity (André and Smulders, 2004; Nakada, 2005; Bretschger and Smulders, 2006). But the empirical examinations state that the assumption of smooth substitution is not hard to realize, especially in the energy industries. With annual time series data for the Canadian metal mining industry for 1954 through 1974, it is shown that the elasticity of substitution between reproducible inputs (capital) and the natural resource, metallic ores are equal to unity (Halvorson and Smith, 1986). This study follows the suggestion of perfect substitution, and assumes the substitution is supported by the technologies carried out by the R&D sector. It suggests the intermediate goods are produced by a Cobb-Douglas function, which allows the elasticity of substitution between capital and energy to be unity.

Meanwhile, many neoclassical analyses contribute to the literature by researching the optimal depletion of exhaustible resources and/or the R&D for so called "backstop technology" (e.g., solar power, nuclear energy), which provides unlimited resources at a constant cost and supports the economic sustainability (Stiglitz, 1974; Dasgupta and Heal, 1974; Solow, 1974; Davidson, 1978). For example, a portion of capital is invested for the R&D to obtain a "resource-independent" technology and the R&D activities cease at the time when the new technology presents (Davidson, 1978). But a more important contribution of Davidson's work is the idea of capital division it suggests.

These neoclassical resource-and-growth models have a common shortcoming that they assume the technological change is exogenous. This drawback is addressed by the endogenous models, which prevail in the 1990s and consider human capital, knowledge spillovers, and constant return to investment as the engines of economic growth. The conventional endogenous R&D model (e.g., Romer, 1990) linked sustained endogenous growth with the idea of expanding product variety. It was extended by examining the innovations as expanding varieties or improvement of quality (Grossman and Helpman, 1991). Though exploring the relationship between endogenous technological changes and the economic growth, these studies do not include energy in their models.

More recently, non-renewable resources are present in various endogenous growth models. The AK approach and Schumpeterian approach connect nonrenewable resources to endogenous growth (Aghion and Howitt, 1998). However, the previous growth models have a common drawback that natural resources neither appear in the "growth engine" (e.g., the education sector producing human capital, the R&D sector providing blueprints), nor act as a necessary ingredient in the production of physical capital which are then used in the R&D sector (Groth and Schou, 2002). They argue that the absence of resources is unlikely, because the educational institutions and research labs use fossil fuels for heating and transportation purposes, or minerals and oil products for machinery, computers, etc. Then their model addresses this shortcoming by applying an increasing return to scale Cobb-Douglas production function with capital, natural resources and increasing labor as inputs.

The conventional R&D model (e.g., Romer, 1990) was extended by assuming energy and physical capital as inputs for intermediate goods (van Zon and Yetkiner, 2003). The model finds that the increasing energy prices erode the profits of producing intermediate goods, discourages the R&D activities, and finally impede the rate of economic growth. Though their model does not include energy as the input for R&D activities, energy contributes to the R&D sector indirectly because the labor doing R&D are compensated by the profit of producing intermediate goods, which use energy as input. At the same time, it breaks the symmetry suggested by the Romer model (1990) and shows an energy-saving technological improvement caused by the growth of energy price. Following van Zon and Yetkiner's suggestion, this study assumes that the intermediate goods are produced by a Cobb-Douglas production function, using raw energy and physical capital as inputs. One may interpret that the "intermediate goods" within this study are actually composite energy services, which are provided by using capital to exploit, extract raw energy. However, unlike the model by van Zon and Yetkiner (2003), the present model follows the symmetry assumption for simplicity.

Furthermore, this study modifies the endogenous R&D model (e.g., Romer, 1990) by introducing the idea of division of capital. Most of the existing R&D models suggest that the capital services of all intermediate goods accumulate the effective capital stock, that is, the whole capital stock only presents in the intermediate goods sector. Nevertheless, it is more realistic to suggest that capital goods might be used in not only the production of intermediate goods but final goods. The suggestion of capital division goes back to researches of the R&D activities for energy (Davison, 1978). It suggests that a proportion of capital is invested for R&D, unlike the previous energy economics literature that usually assumes that the investments for R&D come from forsaking consumption. The present model adopts Davison's assumption---the total capital stock divides into two types of capital: one is used to exploit, extract raw energy, which is used in the production of intermediate goods; the other is invested directly in final good production, in the form of machinery, for example.

By linking energy use and the division of capital with endogenous R&D model, this study gets a result contrasting with the previous literature focusing on energy prices and growth (e.g., van Zon and Yetkiner, 2003). It finds that the growth rate of energy price may stimulate the economic growth. The result consists with the view of "induced technological change" (ITC) or "induced innovation". The normal ITC models concentrate on the transfer between the normal energy technology and the low-carbon energy technology (or the backstop technology). The main view within ITC models is that energy price shock and policy regulation induce the innovations of energy-related technology. One of empirical evidences is found in the research that examines the effect of energy price shock on the energy-efficient innovations using U.S. patent form 1974 to 1994 (Popp, 2002). It finds that the rising energy prices have strongly significant effect on energy-related innovations. But it is pointed out that the ITC literatures concern the innovation in two ways: one focuses on the learning-by-doing effect, which considers the technological progress as black box and ignores the opportunity cost; the other models the R&D, but this kind of models are outside the general macroeconomic framework (Popp, 2004). This study incorporates the R&D for energy technology within the aggregate economic framework and gets a similar conclusion as conventional ITC models.

III. Model

This model considers a closed economy that produces a composite final good. Inputs in the production process are labor, capital and energy, which are denoted by *L* ,*K,* and *E* respectively. *L* is exogenous and constant over time as within the conventional resource economic models. In this study, "energy" may have a broader interpretation, e.g., fuels, precious metals and minerals; and it can be renewable or nonrenewable. It is used in combination with physical capital to produce the intermediate goods. The paper assumes that the quantity (*E*) and price (p_e) of energy supply are exogenous.

3.1 The final output sector

This study applies a Cobb-Douglas production function for final output. It is linear homogeneous in the production factors labor, energy, and intermediate goods. Capital stock is divided into two classes--the capital invested directly in final good production, K_p, and the capital allocated for intermediate goods, K_D. The total capital stock is represented by $K = K_p + K_D$. Hence the output of a representative firm is:

$$Y = AL_P^{\alpha} K_P^{\beta} \int_0^N x_i^{1-\alpha-\beta} \tag{1}$$

In equation (1), L_P is the labor allocated for final goods production; x_i is the *i*th intermediate goods; *α*, *β*, and (1-*α*-*β*) are the partial output elasticity (i.e., the marginal productivity of factor input) of L_P, K_P and x_i respectively; *A* is an overall measure of productivity; and *N* denotes the number of innovations. As within literature of energy economics, labor is assumed to be constant over time because the pressure of sustainability eliminates the possibility of an exponential growth of population. Though *L* is just named "labor" here, one may interpret it as "broad labor", including human capital.

3.2 The intermediate goods sector

A key view within the neoclassical energy economics is that the economic sustainability depends on the degree of substitution between physical capital and energy (or in a broader interpretation, resources) (Victor, 1991). The existing literature indicates that energy is essential for production, that is, the elasticity of substitution between energy and other inputs is less than unity (Dasgupta and Heal, 1974; André and Smulders, 2004; Bretschger and Smulders, 2006). However, energy conservation, energy saving are achieved by substituting capital for energy in general (Nakada, 2005); the present model suggests that the improvements of energy-related technology make the substitution smooth.

Each intermediate goods is produced by a monopolist. Following van Zon and Yetkiner's (2003) model, the present model assumes that the effective services of the intermediate goods are supplied by using K_{Di} and e_i; where K_{Di} and e_i are the capital and raw energy allocated for the *i*th intermediate goods respectively. One may regard the production of x_i as the process of using physical capital to exploit, extract raw energy.

This study assumes that the innovations invented by the R&D sector show the energy technologies that make the substitution between capital and energy easy. Hence the production of x_i is represented by a constant return to scale Cobb-Douglas function:

$$x_i = DK_{Di}^{\delta} e_i^{1-\delta} \tag{2}$$

where δ measures the partial elasticity of capital, and $(1-\delta)$ is the partial elasticity of raw energy; D denotes the 'total-factor' productivity of capital and raw energy.

Substituting (2) into (1), a final output function with two classes of capital and raw energy, besides labor as inputs is obtained as:

$$Y = AL_P^{\alpha} K_P^{\beta} \int_0^N x_i^{1-\alpha-\beta} = AL_P^{\alpha} K_P^{\beta} \int_0^N (DK_{Di}^{\delta} e_i^{1-\delta})^{1-\alpha-\beta} \tag{3}$$

The level of demand for each intermediate follows the first order conditions for a profit maximum of the final output sector. Let $\prod_Y$ denote the profit of the representative final-goods producer, it can be given by

$$\prod_Y = Y - wL_P - rK_P - \int_0^N P_{xi} x_i \tag{4}$$

where w is the wage-rate in the final-goods sector, r is the interest rate, P_{xi} represents the price of the effective energy services of the *i*th intermediate goods. And the price of one unit of final output is normalized as 1.

With the perfect competition on the final output market and the factor input markets, the first order conditions for profit maximization are given by

$$\frac{\partial \prod_Y}{\partial L_P} = \alpha \frac{Y}{L_P} - w = 0 \tag{5}$$

$$\frac{\partial \Pi_Y}{\partial K_P} = \beta \frac{Y}{K_P} - r = 0 \tag{6}$$

$$\frac{\partial \Pi_Y}{\partial x_i} = (1-\alpha-\beta) A L_P^{\alpha} K_P^{\beta} x_i^{-\alpha-\beta} - P_{xi} = 0 \tag{7}$$

Equation (5) and (6) describe that the labor and direct capital input are compensated by their marginal products. This study suggests that the final goods sector determines the interest rate, and the intermediate goods sector takes the interest rate as given.

With (7), the price of x_i is obtained:

$$P_{xi} = (1-\alpha-\beta) A L_P^{\alpha} K_P^{\beta} x_i^{-\alpha-\beta} \tag{8}$$

Equation (8) also shows the demand for x_i given the price P_{xi} required by the monopolist that provides the *i*th intermediate goods. Each intermediate goods is provided by a monopolist; hence, the firm may require a price higher than the cost of producing x_i.

Given the Cobb-Douglas production function for x_i, the cost of producing x_i is denoted by

$$C_{xi} = rK_{Di} + p_e e_i \tag{9}$$

To maximize profits, the monopolist providing intermediates should choose the optimal levels of K_{Di} and e_i that would minimize cost at given factor prices. Therefore, the firms solve the following question:

$$\text{Min } C_{xi} = rK_{Di} + p_e e_i \text{ s.t. } x_i = D K_{Di}^{\delta} e_i^{1-\delta} \tag{10}$$

By solving (10), the trade-off between capital and raw energy is showed by

$$e_i = K_{Di}\left(\frac{r}{p_e}\right)\left(\frac{1-\delta}{\delta}\right) \tag{11}$$

$$K_{Di} = e_i\left(\frac{p_e}{r}\right)\left(\frac{\delta}{1-\delta}\right) \tag{12}$$

Equation (11) indicates that an increase in energy price makes the physical capital more attractive, hence the monopolists may minimize their cost to produce intermediate goods by substituting capital for energy; and vice versa.

Substituting equation (11) and (12) into (9), the cost of producing the *i*th intermediate goods is given by

$$C_{x_i} = \frac{1}{D}(\frac{r}{\delta})^{\delta}(\frac{p_e}{1-\delta})^{1-\delta} x_i \tag{13}$$

Then the cost for one unit of x_i is represented by $\frac{1}{D}(\frac{r}{\delta})^{\delta}(\frac{q}{1-\delta})^{1-\delta}$. It implies that the rises of interest rate and energy price cause the cost of producing one unit of intermediate goods to grow.

In the intermediate goods sector, the firm solves the profit maximizing problem give equation (8) and (13):

$$\Pi_{xi} = P_{xi} x_i - C_{x_i} \tag{14}$$

Then the price of the effective services of the *i*th intermediate good-- P_{xi} and the level of intermediate good are as follows:

$$P_{xi} = \frac{1}{1-\alpha-\beta}\left[\frac{1}{D}(\frac{r}{\delta})^{\delta}(\frac{P_e}{1-\delta})^{1-\delta}\right] \tag{15}$$

$$x_i = \left[\frac{(1-\alpha-\beta)^2 A L_P^{\alpha} K_P^{\beta}}{\frac{1}{D}(\frac{r}{\delta})^{\delta}(\frac{P_e}{1-\delta})^{1-\delta}}\right]^{\frac{1}{\alpha+\beta}} \tag{16}$$

Equations (15) and (16) state that the rising factor prices, would cause the price of intermediate goods to increase, and then reduce the demand for intermediate goods.

The profit of providing x_i is given by

$$\Pi_{xi} = (\alpha+\beta)(1-\alpha-\beta)^{\frac{2}{\alpha+\beta}-1}\left[\frac{1}{D}(\frac{r}{\delta})^{\delta}(\frac{P_e}{1-\delta})^{1-\delta}\right]^{1-\frac{1}{\alpha+\beta}}(A L_P^{\alpha} K_P^{\beta})^{\frac{1}{\alpha+\beta}} \tag{17}$$

This study follows the symmetry assumption (Romer, 1990) that in equilibrium $x_1 = x_2 = x_3 = ... = x_i$, for $1 \le i \le N$; hence, the final output is represented by $Y = A L_P^{\alpha} K_P^{\beta} N x_i^{1-\alpha-\beta}$. Therefore the final goods function is obtained by substituting equation (16) into $Y = AL_P^{\alpha}K_P^{\beta}Nx_i^{1-\alpha-\beta}$:

$$Y = (1-\alpha-\beta)^{\frac{2(1-\alpha-\beta)}{\alpha+\beta}} \left[\frac{1}{D}(\frac{r}{\delta})^{\delta}(\frac{P_e}{1-\delta})^{1-\delta}\right]^{-(\frac{1-\alpha-\beta}{\alpha+\beta})} N(AL_P^{\alpha}K_P^{\beta})^{\frac{1}{\alpha+\beta}} \quad (18)$$

With equation (17) and (18), final output can be represented by

$$Y = \frac{N\prod_{xi}}{(\alpha+\beta)(1-\alpha-\beta)} \quad (19)$$

Equation (20) implies that the growth rate of output equals the sum of the growth rate of innovations and the growth rate of profits for intermediate goods:

$$\hat{Y} = \hat{N} + \hat{\prod}_{xi} \quad (20)$$

where a "∧" denotes the growth rate. The result is consistent to the common notion. Any factor that favors innovations or the oligopolistic rent for providing intermediate goods is likely to promote economic growth. But how the interest rate and energy prices would affect $\hat{N}$ and $\hat{\prod}_{xi}$ is not clear so far. The conventional view is that the rising energy prices deduct the profits of supplying intermediate goods, so energy price shock is harmful to economic growth (van Zon and Yetkiner, 2003). But if the price shock spurs the improvements of energy technology, as ITC models show, the economic growth need not to be hindered.

3.3 The R&D sector

In the R&D sector, research firms carry out R&D activities for energy-related technologies, which support the smooth substitution between capital and raw energy. The only input for R&D activities is labor L_N (or in a broader interpretation, human capital). As in the literature, the change in inventions will be equal to the number of workers in R&D model times the rate at which these workers develop the inventions:

$$\frac{dN}{dt} = \varphi NL_N = \varphi N(L-L_P) \Rightarrow \hat{N} = \varphi(L-L_P) \quad (21)$$

where φ represents the productivity of the R&D process, while a "∧" denotes the growth rate.

The R&D activities are compensated by the oligopolistic profits of providing intermediate goods. Note that the flow of profits is discounted by the interest rate and the growth rate of profits (van Zon and Yetkiner, 2003). Therefore, the expected present value of the *i*th innovation is represented by $\frac{\Pi_{xi}}{r-\hat{\Pi}_{xi}}$. An existing work concentrates on the effect of creative destruction represents the present value of an innovation in the form of $\frac{\Pi_{xi}}{r-\hat{N}}$, but the one this study applies is more straightforward: it implies that if the profit flow of an innovation grows over time, its expected present value would increase (Aghion and Howitt, 1992).

The total cost for R&D is represented by $w_N L_N$, where L_N is the labor allocated for R&D sector, w_N is the wage rate for the workers in R&D sector. Following the free-entry condition of the R&D sector, the cost of doing R&D equals the expected value of the newly developed technologies:

$$w_N L_N = \frac{\Pi_{xi}}{r-\hat{\Pi}_{xi}} \frac{dN}{dt} = \frac{\Pi_{xi}}{r-\hat{\Pi}_{xi}} \varphi N L_N \Rightarrow w_N = \frac{\Pi_{xi}}{r-\hat{\Pi}_{xi}} \varphi N \tag{22}$$

Labor market reaches its equilibrium when the labor allocated in final output sector earns the same wage rate as that of labor doing R&D:

$$w_N = w_P = \alpha \frac{Y}{L_P} \tag{23}$$

With (19), (22) and (23), the labor allocated in final goods sector is obtained as:

$$L_P = \frac{\alpha(r-\hat{\Pi}_{xi})}{\varphi(\alpha+\beta)(1-\alpha-\beta)} \tag{24}$$

Equation (24) states that the labor allocated for final good production is negatively affected by the expected growth rate of the profit flow of innovations. As the profit flow rises over time, doing R&D is more attractive, less labor is allocated for the final goods sector.

3.4 The steady state

This study focuses on the long run status, hence it assumes the steady state exists and pays less attention to the economy along the transition path. If one looks at the adjustment paths leading to long-run equilibrium, factor prices, e.g., the interest rate and the price of energy are allowed to vary. But at the steady state the growth rate of interest is zero, i.e., $\hat{r} = 0$ (Romer, 1990; van Zon and Yetkiner, 2003).

The final output function is derived by substituting $K_P = \beta \frac{Y}{r}$ into equation (18):

$$Y = GN^{\frac{\alpha+\beta}{\alpha}} r^{-[\frac{\beta+\delta(1-\alpha-\beta)}{\alpha}]} P_e^{-[\frac{(1-\delta)(1-\alpha-\beta)}{\alpha}]} L_P \tag{25}$$

where $G = (1-\alpha-\beta)^{\frac{2(1-\alpha-\beta)}{\alpha}} [\frac{1}{D}(\frac{1}{\delta})^{\delta}(\frac{1}{1-\delta})^{1-\delta}]^{-(\frac{1-\alpha-\beta}{\alpha})} A^{\frac{1}{\alpha}} \beta^{\frac{\beta}{\alpha}}$. G is constant given the constant values of $A, D, \alpha, \beta, \varphi$ and δ.

At the steady state, the rate of interest and labor in the final output sector are constant. With $\hat{L}_P = 0$, $\hat{r} = 0$ and equation (25), the growth rate of output at steady state can be represented by

$$\hat{Y} = \frac{\alpha+\beta}{\alpha}\hat{N} - \frac{(1-\delta)(1-\alpha-\beta)}{\alpha}\hat{P}_e \tag{26}$$

It seems that the growth of energy price has a negative effect on economic growth. However, if the energy price shock stimulates the innovations for energy technology, the conclusion is converted.

With equation (20), (21), (24) and (26), the growth rates of output, innovation and profit flow are respectively given by

$$\hat{Y} = \frac{\alpha+\beta}{\alpha}\varphi L(1+\frac{\beta}{z}) - \frac{\alpha+\beta}{z}r - \frac{(1-\delta)(1-\alpha-\beta)}{\alpha}(1+\frac{\alpha+\beta}{z})\hat{P}_e \tag{27}$$

where $z = (\alpha+\beta)(1-\alpha-\beta) - \beta$.

So far this study shows the supply side of the economy; the demand side can be presented by the Ramsey model that solves the problem of maximizing utility of consumption. The individual's utility function takes the form $U = \int_{t=0}^{\infty} e^{-\rho t} u(C(t))dt$, where ρ is the discount rate, $C(t)$ is the individual's consumption. Following the Ramsey model, the growth rates of output and consumption are given by

$$\hat{Y} = \hat{C} = \frac{r-\rho}{\theta} \tag{28}$$

In equation (28), $\sigma = \frac{1}{\theta}$ represents the elasticity of substitution between consumption at any two points in time.

Hence with equation (27) and (28), the interest rate, the growth rates of output, innovations and profits of producing intermediate goods at the steady state are obtained as follows:

$$r^* = \frac{\theta}{z+\theta(\alpha+\beta)}\left[\frac{\alpha+\beta}{\alpha}\varphi L(z+\beta) - \frac{(1-\delta)(1-\alpha-\beta)}{\alpha}(z+\alpha+\beta)\hat{P}_e + \frac{z\rho}{\theta}\right] \tag{29}$$

$$\hat{Y}^* = \frac{1}{z+\theta(\alpha+\beta)}\left[\frac{\alpha+\beta}{\alpha}\varphi L(z+\beta) - \frac{(1-\delta)(1-\alpha-\beta)}{\alpha}(z+\alpha+\beta)\hat{P}_e - (\alpha+\beta)\rho\right] \tag{30}$$

$$\hat{N}^* = \frac{1}{z+\theta(\alpha+\beta)}[\varphi L(z+\beta) + (1-\delta)(1-\alpha-\beta)(\theta-1)\hat{P}_e - \alpha\rho] \tag{31}$$

$$\hat{\Pi}_{xi}^* = \frac{1}{z+\theta(\alpha+\beta)}\left[\frac{\beta}{\alpha}\varphi L(z+\beta) - \frac{(1-\delta)(1-\alpha-\beta)}{\alpha}(z+\beta+\alpha\theta)\hat{P}_e - \beta\rho\right] \tag{32}$$

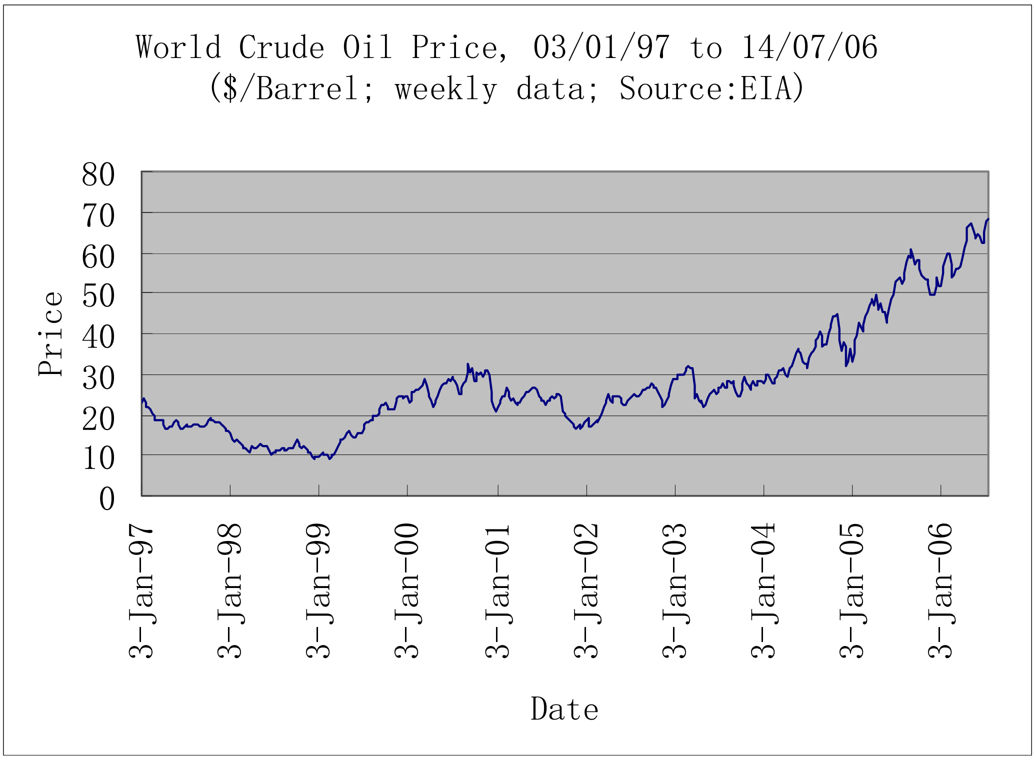
Within the endogenous growth literatures that focus on R&D effect, the increase in factor prices usually discourage economic growth (Romer, 1990; van Zon and Yetkiner, 2003). The reason is that the rising factor prices (e.g., interest rate and energy prices) erode the pay back of doing R&D, and then impede economic growth. But the present paper needs not to follow the previous views. Given $1-\delta > 0$, $1-\alpha-\beta > 0$, and $z+\alpha+\beta = (\alpha+\beta)(1-\alpha-\beta)+\alpha > 0$, equation (30) shows that whether the growth rate of energy prices has positive or negative impact on the rate of economic growth depends on the sigh of $z+\theta(\alpha+\beta)$, or in others words, depends on the values of α, β, and θ. Section 3.5 presents how the values of α, β, and θ affect the sign of $\frac{d\hat{Y}}{d\hat{P}_e}$ (i.e., how energy price increases affect the growth rate of output).

3.5 Discussions

Figure 1 presents the world prices of crude oil from 1997 to 2006. It shows that the prices keep rising, especially since 2003. The price reached a new historical high on

July 14, 2006 (76.80$/Barrel, Cushing, OK WTI Spot Price FOB; 76.13$/Barrel, Europe Brent Spot Price FOB; Source: EIA). Notwithstanding the increasing energy prices, world output growth rate is not bad: 5.3% for 2004, 4.8% for 2005, and 4.9% for 2006 (projected) (*World Economic Outlook Globalization and Inflation*, April 2006, IMF). Other than applying an econometric approach, the present paper sets values for parameters and discusses how the growth rate of energy prices affect the rate of output growth.

Figure 1.



Before it sets the values for parameters, this study reviews the values that are used in previous literature. Frequently, in a constant return to scale Cobb-Douglas production function with labor and capital as inputs (e.g., $Y = AL^{\alpha}K^{\beta}$; *K*—physical capital, *L*—labor, including human capital), the values of parameters used are $\alpha = 2/3$ and $\beta = 1/3$ (Barro and Sala-i-Martin, 1995), the output elasticity of labor is about two times of that of capital. In the cases that resources (or energy) are included in the production function (e.g., $Y = AL^{\alpha}K^{\beta}E^{1-\alpha-\beta}$), the existing literatures suggest that the productivity of capital is as about four times large as that of resources (Solow, 1974a; Hartwick, 1977; Dasgupta and Heal, 1979). An econometric estimation by Slade (1987) reports that output share of capital and that of resources are approximately equal. But Neumayer (2000) suggests that the share of capital is considerably higher than that of resources; Slade ignores the intermediate goods that are produced by capital, and gets the inaccurate result. In an article considering two models of energy use and using annual data for the U.S. economy for the period

1960-1994 (Atkeson and J. Kehoe, 1999), the output elasticities with respect to labor, capital and energy are 0.57, 0.387 and 0.043 respectively. A more current study applying an increasing return to scale production function (Groth and Schou, 2002) suggests a case in which the output elasticity of energy can be a larger value (greater than 0.05), if the environment is considered. However, this study uses a constant return in scale; the output elasticity of energy cannot be a very large value.

Hence, summing the suggestions of Dasgupta and Heal (1979), Barro and Sala-i-Martin (1995), Atkeson and Kehoe (1999), Groth and Schou (2002), this study sets the baseline values of parameters as follows: $\alpha = 0.6$, $\beta = 0.3$. And the output elasticity for the intermediate goods is 0.1.

At the equilibrium, the final output function that is used in this study is rewritten as $Y = AL_P^{\alpha} K_P^{\beta} ND^{1-\alpha-\beta} K_{Di}^{\delta(1-\alpha-\beta)} e_i^{(1-\delta)(1-\alpha-\beta)}$; hence, the output elasticity with respect to energy is represented by $(1-\delta)(1-\alpha-\beta)$. Given $\alpha = 0.6$, $\beta = 0.3$ and $0 < 1-\delta < 1$, the range of $(1-\delta)(1-\alpha-\beta)$ is 0~0.1, which reconciles the values reported by literature. Since the sign of $z + \theta(\alpha + \beta)$, which this study is going to discuss in this section, is independent on the value of δ, this study supposes that δ is constant. One might expect that a higher/lower ($1-\alpha-\beta$) leads to a higher/lower output elasticity of energy. Hence, for simplicity, this study uses ($1-\alpha-\beta$) rather than $(1-\delta)(1-\alpha-\beta)$ to represent the output elasticity of energy. Furthermore, since this study concentrates on the substitution between capital and energy, it suggests that α is fixed, and discusses the trade-off between β and ($1-\alpha-\beta$), which may cause a greater of smaller output elasticity of energy.

Although the literatures set lower value for σ ($\sigma = \frac{1}{\theta}$), e.g., $\sigma = 0.5$ (Barro and Sala-i-Martin, 1995), $0.33 < \sigma < 0.9$ (Fullerton and Kim, 2006), this study chooses a higher value for σ. It suggests that the society requires a sufficiently large intertemporal substitution elasticity to postpone current consumption, investing more for production to overcome the negative impact of the increasing energy prices. It is obvious that if σ is only 1, definitely the sign of $z + \theta(\alpha + \beta)$ is positive, which implies that the society could not deal with the energy shocks. Therefore, the baseline value for σ is 5 within the present model.

Table 1 summarizes the results under the cases with different values for β given α =

0.6 and $\sigma = 5$. In the table, '+' and '-' represent the sign of $\frac{d\hat{Y}}{d\hat{P}_e}$, $\frac{d\hat{N}}{d\hat{P}_e}$ and $\frac{d\hat{\Pi}_{xi}}{d\hat{P}_e}$.

The baseline case shows that the growth rate of energy prices is possibly to stimulate the_economic growth, because it has positive impacts on innovations and the profits for doing R&D. In the case that the output elasticity of energy is sufficient small (low $(1-\alpha-\beta)$ given δ is fixed), energy is not so crucial to production. On the other hand, if the output elasticity of energy is sufficiently large, the continuously increasing prices of energy are harmful to the growth rate of output.

Table 1
Effects of the values of output elasticities of labor, capital and energy with $\sigma = 5$

Cases	$\frac{d\hat{N}}{d\hat{P}_e}$	$\frac{d\hat{\Pi}_{xi}}{d\hat{P}_e}$	$\frac{d\hat{Y}}{d\hat{P}_e}$
Baseline $\alpha = 0.6$, $\beta = 0.3$, $\sigma = 5$	+	+	+
Higher output elasticity of capital & Lower output elasticity of energy Fixed σ and output elasticity of labor $\alpha = 0.6$, $\beta = 0.35$, $\sigma = 5$	+	+	+
Lower output elasticity of capital & Higher output elasticity of energy Fixed σ and output elasticity of labor $\alpha = 0.6$, $\beta = 0.25$, $\sigma = 5$	-	-	-
$\alpha = 0.6$, $\beta = 0.20$, $\sigma = 5$	-	-	-

Table 2 summarizes the results of the cases with different values of σ given $\alpha = 0.6$ and $\beta = 0.3$. In the present model, σ represents the intertemporal substitution elasticity. A higher σ implies that consumers put a lower weight on smoothing utility over time, and are more willing to postpone consumption to a later date. Hence, the society would invest more in production, and anticipate a higher rate of economic growth in the future. The baseline case shows that given a sufficiently high value of σ, the growth rate of energy prices may has positive effect on the rate of economic growth, because it favorites innovations and increases the profits for producing innovations. In the case that the intertemporal substitution elasticity is low

($\sigma = 4, 3, 2, 1...$), the substitution between consumption at any two points in time is relatively difficult. In such cases, the investment, and then the economic growth are impeded by the growth rate of energy prices.

Table 2

Effects of the value of σ given $\alpha = 0.6$ and $\beta = 0.3$

Cases	$\frac{d\hat{N}}{d\hat{P}_e}$	$\frac{d\hat{\Pi}_{xi}}{d\hat{P}_e}$	$\frac{d\hat{Y}}{d\hat{P}_e}$
Baseline			
$\alpha = 0.6$, $\beta = 0.3$, $\sigma = 5$	+	+	+
Higher σ			
Fixed output elasticities of labor, capital and energy			
$\alpha = 0.6$, $\beta = 0.3$, $\sigma = 6$	+	+	+
Lower σ			
Fixed output elasticities of labor, capital and energy			
$\alpha = 0.6$, $\beta = 0.3$, $\sigma = 4$	-	-	-
$\alpha = 0.6$, $\beta = 0.3$, $\sigma = 3$	-	-	-

Comparing to the baseline values, one may find that if $(1-\alpha-\beta)$ is lower, say, 0.05, the value of $\frac{1}{\sigma}$ required to hold $z + \theta(\alpha+\beta) < 0$ and $\frac{d\hat{Y}}{d\hat{P}_e} > 0$ is lower ($\sigma > 2.98$). On the other hand, if σ is larger, say, 6, $\frac{d\hat{Y}}{d\hat{P}_e} > 0$ is held even though $(1-\alpha-\beta)$ is 0.13. It implies that if a society has a low output elasticity of raw energy, relatively lower intertemporal substitution elasticity is required to sustain economic growth under the shock of energy price. If a society puts a low weight on smoothing utility over time and are eager to anticipate future gains by decreasing current consumption and investing, energy price shock would not obstruct the rate of economic growth, even if the output elasticity of raw energy is high and vice versa.

So far, this study shows that if σ is sufficiently large, $(1-\alpha-\beta)$ is sufficiently small, or both conditions are held, one may get $z+\theta(\alpha+\beta)<0$, where

$z=(\alpha+\beta)(1-\alpha-\beta)-\beta$. Hence, $\frac{d\hat{Y}}{d\hat{P}_e}>0$, $\frac{d\hat{N}}{d\hat{P}_e}>0$ and $\frac{d\hat{\prod}_{xi}}{d\hat{P}_e}>0$ are obtained.

It implies that the rate of economic growth may depend positively on the rate of growth of energy prices, suggesting that the continuously rising energy prices will tend to spur economic growth. The result contrasts with the modern endogenous growth literature. However, the result verifies the view of ITC: to counteract the energy price impact, more inputs are allocated for R&D, which supply the technology to alleviate the negative effect of price shock; therefore, more innovations are created and the economic growth is accelerated.

This study finds that the growth rate of energy prices does not need to impede the rate of economic growth. It applies a Cobb-Douglas production function that allows smooth substitution between different factors. As the price of raw energy rises, within the intermediate goods sector, the firms substitute capital for raw energy; while in the final goods sector, the firms substitute capital for intermediate goods. However, three conditions have to be met to avoid the crisis caused by energy price shock: first, the partial output elasticity of energy should be sufficiently small; secondly, the elasticity of substitution between consumption at any two points in time, σ, is sufficiently high; finally, the growth rate of energy prices should not be too high for the following reason:

The labor allocated for the R&D sector is given by

$$L_P=\frac{1}{z+\theta(\alpha+\beta)}[L(\theta(\alpha+\beta)-\beta)-\frac{(1-\delta)(1-\alpha-\beta)(\theta-1)}{\varphi}\hat{P}_e+\frac{\alpha}{\varphi}\rho] \qquad (33)$$

Given the baseline values for parameters that is used within the present paper, one might get $z+\theta(\alpha+\beta)<0$, $(1-\delta)(1-\alpha-\beta)>0$, and $\theta-1<0$. Hence, equation (33) implies that $\frac{dL_P}{d\hat{P}_e}<0$ can be held. As $\hat{P}_e$ keeps increasing, more and more labor are allocated for R&D activities to overcome the negative impact of continuously rising energy prices, the labor allocated for the final output sector would be close to zero; and then the economy is broken down because labor is essential to the production of final goods. Note that the domain of L_P should be $L>L_P>0$.

IV. The policy implications

A common view within the endogenous growth literature is that interest income taxes discourage economic growth while investment subsidies promote economic growth (Lucas, 1990; King and Rebelo, 1990; Rebelo, 1991; Jones et al., 1993; Barro and Sala-i-Martin, 1995; Stokey and Rebelo, 1995; Milesi-Ferretti and Roubini, 1998; Aghion and Howitt, 1998). By introducing the idea of capital division and including energy into the production of intermediate goods, this study shows that the common view may be held but some conditions are required.

The impacts of energy conservation policies have been discussed for a long time. There are disagreements as to the sign of the effects: one side holds that imposing taxes on energy use (e.g., a carbon tax) works as increasing energy prices, which lowers the profits of using new intermediate goods and the profits of doing research, therefore impedes the growth rate of output (Smulders and de Nooij, 2003; van Zon and Yetkiner, 2003). But the studies focusing on ITC have reported that environmental policies induce the improvements of energy-related technologies that make the regulations less costly (Lanjouw and Mody, 1996; Jaffe and Palmer, 1997; Newell, Jaffe, and Stavins, 1999; Popp, 2002 and 2004). Within the framework of endogenous R&D growth, the present model gets the similar result as that of ITC models, but it also indicates that the energy conservation tax promotes economic growth only if the tax rate is increasing over time, and the values of ($\alpha+\beta$), and σ are sufficiently high.

In general, energy conservation is achieved by substituting capital for energy (Nakada, 2005). Therefore, this study suggests a conservation policy that taxes energy consumption and subsidizes capital use. The tax rate is τ ($\tau>0$); let $\tau'=(1+\tau)$, then the cost of using one unit of energy after tax is represented by $\tau' P_e$. Note that the present model suggests that the tax rate can be time-varying, that is, $\hat{\tau}'=0$ is not required. This study demonstrates that such a tax promotes economic growth as it finds there is a positively sloped relation between the rate of economic growth and the growth rate of energy prices (given $\alpha+\beta$ and σ are high enough to ensure $z+\theta(\alpha+\beta)<0$). A time-increasing energy tax works as a device that accelerates the growth rate of energy prices.

Similarly, the subsidy rate is s $(s>0)$; let $s'=1+s$, so the cost of using one unit of capital is $s'r$. This study assumes that $\hat{s}'=0$ is not necessary to be held. The budget constraint is given by $\tau P_e E+T=srK$, where T is a lump sum tax (amounting to a transfer, if negative).

Under the regulation, the demand for the *i*th intermediate goods and the profit of providing the *i*th intermediate goods are given as follows:

$$x_i = \left[\frac{(1-\alpha-\beta)^2 A L_P{}^{\alpha} K_P{}^{\beta}}{\frac{1}{D}\left(\frac{(1+\tau)P_e}{1-\delta}\right)^{1-\delta}\left(\frac{(1-s)r}{\delta}\right)^{\delta}} \right]^{\frac{1}{\alpha+\beta}} \quad (34)$$

$$\Pi_{xi} = (\alpha+\beta)(1-\alpha-\beta)^{\frac{2}{\alpha+\beta}-1}\left(A L_P{}^{\alpha} K_P{}^{\beta}\right)^{\frac{1}{\alpha+\beta}}\left[\frac{1}{D}\left(\frac{(1+\tau)P_e}{1-\delta}\right)^{1-\delta}\left(\frac{(1-s)r}{\delta}\right)^{\delta}\right]^{1-\frac{1}{\alpha+\beta}} \quad (35)$$

Following the process presented before to derive economic growth, the new economic growth rate under the regulation is given by

$$\hat{Y} = \frac{\alpha+\beta}{\alpha}\varphi L(1+\frac{\beta}{z}) - \frac{\alpha+\beta}{z}r - \frac{(1-\alpha-\beta)}{\alpha}(1+\frac{\alpha+\beta}{z})[(1-\delta)(\hat{\tau}'+\hat{P}_e)+\delta\hat{s}'] \quad (36)$$

The return of capital is shown by $r = \beta\frac{Y}{K_P}$; hence the demand side of the economy is represented by $\hat{Y} = \frac{r-\rho}{\theta}$. Substituting it into equation (36), the long run interest rate and the growth rate of output under the regulation are obtained

$$r^{**} = \frac{\theta}{z+\theta(\alpha+\beta)}\left[\frac{\alpha+\beta}{\alpha}\varphi L(z+\beta) - \frac{(z+\alpha+\beta)(1-\alpha-\beta)}{\alpha}[(1-\delta)(\hat{\tau}'+\hat{P}_e)+\delta\hat{s}'] + \frac{z\rho}{\theta}\right] \quad (37)$$

$$\hat{Y}^{**} = \frac{1}{z+\theta(\alpha+\beta)}\left[\frac{\alpha+\beta}{\alpha}\varphi L(z+\beta) - \frac{(z+\alpha+\beta)(1-\alpha-\beta)}{\alpha}[(1-\delta)(\hat{\tau}'+\hat{P}_e)+\delta\hat{s}'] - (\alpha+\beta)\rho\right] \quad (38)$$

Equation (38) shows the effects of capital subsidy and energy tax on the growth rate of output. It implies that the subsidy and tax do not affect long run rate of economic growth unless their rates are time-varying.

As the discussions in section 3.5, given a sufficiently low value for $(1-\alpha-\beta)$ or a sufficiently high σ or both, $z+\theta(\alpha+\beta)<0$ is obtained; hence, $\frac{d\hat{Y}^{**}}{d\hat{P}_e} > 0$,

$\frac{d\hat{Y}^{**}}{d\hat{\tau}'} > 0$, $\frac{d\hat{Y}^{**}}{d\hat{\tau}} > 0$ (note that $\tau' = 1 + \tau$), $\frac{d\hat{Y}^{**}}{d\hat{s}'} > 0$ and $\frac{d\hat{Y}^{**}}{d\hat{s}} < 0$ (note that $s' = 1 - s$). In this case, the tax for energy use promotes the growth rate of output. The reason lies in that the energy conservation policy has two kinds of effects: the tax causes the cost of producing the intermediate goods to rise, and hence reduces the demand for the composite energy services provided by the intermediates; on the other hand, the tax means the real energy price grows, and then stimulates the innovations. Given low $(1 - \alpha - \beta)$ and/or high σ, the positive impact overcomes the negative one; a higher growth rate of output is obtained. However, the subsidy for capital has a negative effect in this case. Therefore, in the case that the effect of induced technological change (caused by energy price shock) dominates, an increasing tax on energy use and a constant subsidy for capital use are called for.

Similarly, if $z + \theta(\alpha + \beta) > 0$, equation (38) implies that $\frac{d\hat{Y}^{**}}{d\hat{P}_e} < 0$, $\frac{d\hat{Y}^{**}}{d\hat{\tau}'} < 0$, $\frac{d\hat{Y}^{**}}{d\hat{\tau}} < 0$, $\frac{d\hat{Y}^{**}}{d\hat{s}'} < 0$ and $\frac{d\hat{Y}^{**}}{d\hat{s}} > 0$. In this case, the increasing subsidy on capital use results in a higher growth rate of output. On the contrary, the energy tax has a negative effect on the growth rate of output. The reason lies in that in this case, the contribution of energy to output is large; and the energy tax are transferred into corresponding output shock through the channel of energy use in the intermediate goods sector, and the composite energy services in the final output level. Therefore, if $z + \theta(\alpha + \beta) > 0$, the policy maker should apply an increasing subsidy for capital use and a constant tax rate for energy use.

Note that the subsidy for capital use and the tax on energy consumption should be moderate even though they might favor the rate of economic growth. The reason lies in that the subsidy and the tax may have negative impacts on labor allocated in the final output sector as follow:

$$L_P = \frac{1}{z + \theta(\alpha + \beta)}[L(\theta(\alpha + \beta) - \beta) - \frac{(1 - \alpha - \beta)(\theta - 1)}{\varphi}[(1 - \delta)(\hat{\tau}' + \hat{P}_e) + \delta \hat{s}'] + \frac{\alpha}{\varphi}\rho] \tag{39}$$

In the case that $z + \theta(\alpha + \beta) < 0$, $\frac{dL_P}{d\hat{\tau}} < 0$ is held,; while if $z + \theta(\alpha + \beta) > 0$, $\frac{dL_P}{d\hat{s}} < 0$. An extremely high tax/subsidy rate results in insufficient labor is allocated for the final output sector and destroys the economy; therefore, a moderate policy is called for.

V. Concluding remarks

This study links energy use and the division of capital stock with endogenous R&D model. The conventional endogenous R&D model (Romer, 1990) is modified by including energy use in the production of intermediate goods; meanwhile, capital is divided into two classes—one is invested in final goods sector directly, the other is allocated for the production of intermediate goods. It assumes that the energy-related innovations carried by the R&D sector support the smooth substitution between capital and energy, hence both intermediate and final goods production sectors apply the Cobb-Douglas production function.

Contrasting with the existing literature, the present model finds that the growth rate of energy prices needs not to impede the rate of output growth. If the partial output elasticity of energy is sufficiently low or the elasticity of substitution of consumption between any two points in time is sufficiently large, or both conditions are satisfied, the continuously increasing energy price has an effect similar to so called induced technological change (ITC), which spurs the innovations for energy technology and then promotes the rate of economic growth.

For the sake of energy conservation, this study suggests a policy that imposes a tax on energy use and subsidizes capital use. Unlike existing literature asserting that capital subsidy stimulates economic growth, this study finds that such a subsidy works only if it is time-varying, and the output elasticity of energy is high, and/or the elasticity of intertemporal substitution is low. If the conditions are not met, an increasing energy conservation tax and a constant capital subsidy rate are required to stimulate innovations, and then favor the growth rate of output. Besides, the policy should be moderate, because the high energy tax or capital subsidy rate causes more and more labor to enter the R&D sector and therefore the labor in the final output sector is insufficient.

References:

Aghion, Philippe, and Peter Howitt, 1992: “A model of growth through creative destruction,” *Econometrica*, 60 (2): 323–351.

Aghion, Philippe and Peter Howitt, 1998: *Endogenous Growth Theory*, MIT Press, Cambridge, MA.

Andre, Francisco J. and Sjak Smulders, 2004: “Energy use, endogenous technical change and economic growth,” http://www.feem-web.it/ess04/contents/smulders3.pdf.

Atkeson, Andrew and Patrick J. Kehoe, 1999: “Models of energy use: Putty-putty versus putty-clay,” *American Economic Review*, 89 (4): 1028-1043.

Barro, R. and X. Sala-i-Martin, 1995: *Economic Growth*, McGraw-Hill, New York.

Bretschger, Lucas and Sjak Smulders, 2006: “Sustainability and substitution of exhaustible natural resources: How resource prices affect long-term R&D-investments,” *Economics Working Paper Series* 03/26, ETH Zurich.

Dasgupta, Partha and Geoffrey Heal, 1974: “The optimal depletion of exhaustible resources,” *Review of Economic Studies*, Symposium Issue, 41: 3-28.

Dasgupta, P.S., and G. M. Heal, 1979: *Economic Theory and Exhaustible Resources*, Cambridge University Press

Davison, R. 1978: “Optimal depletion of an exhaustible resource with research and development towards an alternative technology,” *Review of Economic Studies*, 45(2): 355-367.

Fullerton, Don and Seung-Rae Kim, 2006: “Environmental investment and policy with distortionary taxes endogenous growth,” NBER Working paper 12070, http://www.nber.org/papers/w12070.

Grossman, Gene M., and Elhanan Helpman, 1991: *Innovation and Growth in the Global Economy*. Cambridge, Mass.: MIT Press.

Groth, Christian and Poul Schou, 2002: "Can non-renewable resources alleviate the knife-edge character of endogenous growth? *Oxford Economic Papers,* 54(3): 386-411.

Halvorson, Robert and Tim R. Smith, 1986: “Substitution possibilities for unpriced natural resources: Restricted cost functions for the Canadian metal mining industry,” *Review of Economics and Statistics*, 68(3): 398-405.

Hartwick, J.M. (1977): “Intergenerational equity and the investing of rents from exhaustible resources,” *American Economic Review*, 67(5): 972-974.

Herfindahl, O. and A. Kneese, 1974: *Economic Theory of Natural Resources*. Columbus: Merrill.

Hotelling, Harold, 1931: “The economics of exhaustible resources,” *Journal of Political Economy*, 39(2): 137-175.

Jaffe, Adam B. and Karen Palmer, 1997: "Environmental regulation and innovation: A panel data study," *Review of Economics and Statistics*, 79(4): 610-619.

Jones, L.E., R.E. Manuelli, and P.E. Rossi, 1993: “Optimal taxation in models of endogenous growth,” *Journal of Political Economy*, 101: 485–517.

King, Robert G., and Sergio T. Rebelo (1990): "Public policy and economic growth: Developing neoclassical implications," *Journal of Political Economy*, 98(5): S127-S150.

Lanjouw, J. O. and Ashoka Mody, 1996: "Innovation and the international diffusion of environmentally responsive technology," *Research Policy*, 25: 549-71.

Lucas, R.E. Jr, 1990: “Supply-side economics: An analytical review,” *Oxford Economic Papers*, 42: 293–316.

Milesi-Ferretti, G.M. and N. Roubini (1998): “On the taxation of human and physical capital in models of endogenous growth,” *Journal of Public Economics*, 70: 237-254.

Nakada, Minoru, 2005: “Deregulation in an energy market and its impact on R&D for low-carbon energy technology,” *Resource and Energy Economics*, 27: 306-320.

Neumayer, Eric, 2000: “Scarce or abundant? The economics of natural resource availability,” *Journal of Economic Surveys*, 14(3): 307-335.

Newell, Richard G, Adam B. Jaffe, and Robert N. Stavins, 1999: “The induced innovation hypothesis and energy-saving technological change,” *Quarterly Journal of Economics*, 114(3):941-975.

Popp, David, 2002: “Using patents to measure technological change: Lessons for climate policy”, Working Paper, http://www.uni-oldenburg.de/speed/workshop/xdocs/pdf/Popp_Paper_02.pdf.

Popp, David, 2004: “ENTICE-BR: The Effects of Backstop Technology R&D on Climate Policy Models,” NBER Working Paper

10285, http://www.nber.org/papers/w10285.

Rebelo, Seigio, 1991: "Long-run policy analysis and long-run growth," *Journal of Political Economy*, 99(3): 500-521

Romer, Paul M., 1990: "Endogenous technological change," *Journal of Political Economy*, 98(5): 71-102.

Scholz, Christian M., and Georg Ziemes, 1999: "Exhaustible resources, monopolistic competition, and endogenous growth," *Environmental and Resource Economics*, 13: 169-185.

Schou, Poul, 2000: "Polluting nonrenewable resources and growth," *Environmental and Resource Economics*, 16: 211-227.

Smulders, Sjak and Michiel de Nooij, 2003: "Induced technological change, energy, and endogenous growth," *Resource and Energy Economics*, 25: 59–79.

Slade, M.E. (1987): "Natural resources, population growth, and economic well-being," in D. G. Johnson and R. D. Lee (eds.) *Population Growth and Economic Development*: *Issues and Evidence*, Wisconsin: University of Wisconsin Press, 331-369.

Solow, R. W., 1974: "The economics of resources or the resources of economics," *American Economic Review*, 64(2): 1-14.

Solow, R. (1974a), 'Intergenerational Equity and Exhaustible Resources', *Review of Economic Studies*, Symposium Issue, 41: 29-45.

Stiglitz, J., 1974: "Growth with exhaustible natural resources: efficient and optimal growth paths," *Review of Economic Studies*, Symposium Issue, 41: 123-137.

Stokey, N. L. and S. Rebelo, 1995: "Growth effects of flat-rate taxes," *Journal of Political Economy*, 103: 519-550.

van Zon, Adriaan and I. Hakan Yetkiner, 2003: "An endogenous growth model with embodied energy-saving technical change," *Resource and Energy Economics*, 25: 81–103.

Victor, Peter A., 1991: "Indicators of sustainable development: Some lessons from capital theory," *Ecological Economics*, 4(3): 191-213.

Full paper submission for the 1st Congress of East Asian Association of Environmental and Natural Resource Economics, Hokkaido University, Japan

Practices and Opportunities of Green Supply Chain Management in China

Xianbing LIU[a, *], Leina WANG[b], Jie YANG[b], Tomohiro SHISHIME[a], Cunkuan BAO[b], Kazunori OGISU[a]

[a] Kansai Research Centre, Institute for Global Environmental Strategies (IGES), Japan

[b] College of Environmental Science and Engineering, Tongji University, China

Corresponding Author: Xianbing Liu

Postal Address: Kansai Research Centre, Institute for Global Environmental Strategies (IGES),
Hitomirai Building 4F, 1-5-2, Wakinohama Kaigan Dori,
Chuo-ku, Hyogo, 651-0073, JAPAN
Tel: +81-78-262-6634; Fax: +81-78-262-6635

E-Mail Address: liu@iges.or.jp

[Abstract] As a part of a project exploring proactive strategies for improving corporate environmental management (CEM) in developing Asia, this paper introduces the practices and opportunities of green supply chain management (GSCM) in China. Yangtze River Delta, where the economy has been relatively developed, was selected as our study area. We conducted the study by two steps. At the first phase, a questionnaire survey to the companies was carried out in order to monitor the overall level of GSCM practices there. The determinant factors of GSCM practices were identified by econometric analyses of the data collected from 165 valid respondents. As the second step, three representative companies were picked up as focal manufacturers for case studies in more details. Their current activities and future opportunities of GSCM were individually identified. The corresponding cost and benefit of GSCM practices was analyzed descriptively or quantitatively.

Our survey confirms that Chinese companies are still at a preliminary stage of GSCM practices. Their environmental efforts in cooperation with external members of supply chain are marginal. The regulative requirements, demands of domestic clients and the practices of competitors are external factors significantly and positively associated with a firm GSCM practice level. A firm's internally environmental management capacity works as a mediator of external pressures in influencing its actual GSCM efforts. The case studies also indicate that the target companies mainly focus on voluntary and internal GSCM activities like cleaner production and energy saving audit. These activities help the companies improve their economic and environmental performances. The case analysis shows that industrial sector characteristics and company's location on the supply chain greatly affect the level GSCM practices. Two typical patterns of GSCM practices may be summarized from the case studies. One is a relatively mature GSCM relationship which is driven by market strategy and involvement of multi-national companies. Another is a government policy-driven style for the domestic companies.

***Key words*:** Green supply chain management, survey study, China

1. Introduction

Out of all business operations, manufacturing processes are viewed to have the most impacts on the environment, in the forms of pollutants generation, ecosystem disruption and depletion of natural resources (Fiksel, 1996). The pressures and drivers accompanying globalization have encouraged manufacturers in developing economies like China to improve their environmental performances (Zhu and Sarkis, 2006). Accordingly, environmental concerns gradually become part of overall corporate culture and, in turn, help reengineer the development strategies of corporations (Madu et al., 2002). Corporate environmental management (CEM) is moving from pollution control and risk management towards product life cycle management and industrial ecology. In recent years, CEM has evolved to include certain boundary-spanning activities like green procurement, product stewardship and reverse logistics, etc. (Zsidisin and Siferd, 2001; Snir, 2001; Prahinski and Kocabasoglu, 2006). These practices are related to supply chain management, which needs various interactions between the core manufacturers and the other entities along the supply chain, either the upstream suppliers or downstream customers. Green supply chain management (GSCM) was defined as a new phrase by the Manufacturing Research Association in Michigan State University of US. (Handfield, 1996).

The rapid economic growth of China has greatly relied on the extensive expansion of manufacturing industries which provide resource-intensive but cheap goods for foreign markets. The relatively high position of Chinese manufacturers in the global supply chain offers the possibility and an ideal setting for exploring their actual GSCM practices. Zhu et al. (2008) studied the emergent GSCM practices at company level in the Chinese context, and found that GSCM is still a new concept for Chinese firms as they change their environmental efforts from internal improvement to the entire supply chains. Regarding the determinant factors for GSCM practices, the previous study mainly focused on a firm’s internal issues such as the importance of a firm’s learning oriented programs and support of top managers. The pressures from external stakeholders bear further investigations due to their importance to a firm’s environmental behaviors according to the institutional theory (Zhu et al., 2008). As the previous study was conducted in Northern cities of China (Zhu et al., 2008), additional surveys of the companies based in the other geographical areas, such as the Southern Yangtze River delta which is a representative economic zone in China, would be interesting and necessary.

In order to close the research gap described above, this paper identifies the practices and opportunities of GSCM in China. Yangtze River delta close to Shanghai is selected as the study area due to its relatively developed economy compared with other regions of China. The improved background of CEM provided the possibility of monitoring a firm’s GSCM activities there. Two topics are mainly discussed in this paper: a) Overall status of GSCM practices of the firms in the study area and analysis of the determinant factors by questionnaire survey; b) Effectiveness and future opportunities of GSCM practices by specific case studies.

2. The questionnaire survey monitoring overall status of GSCM practices of firms

2.1 Analytical framework developed for the questionnaire survey

Figure 1 depicts the analytical framework for the questionnaire survey and analysis, in which the relationships between the determinant factors and a firm's GSCM activities are discussed.

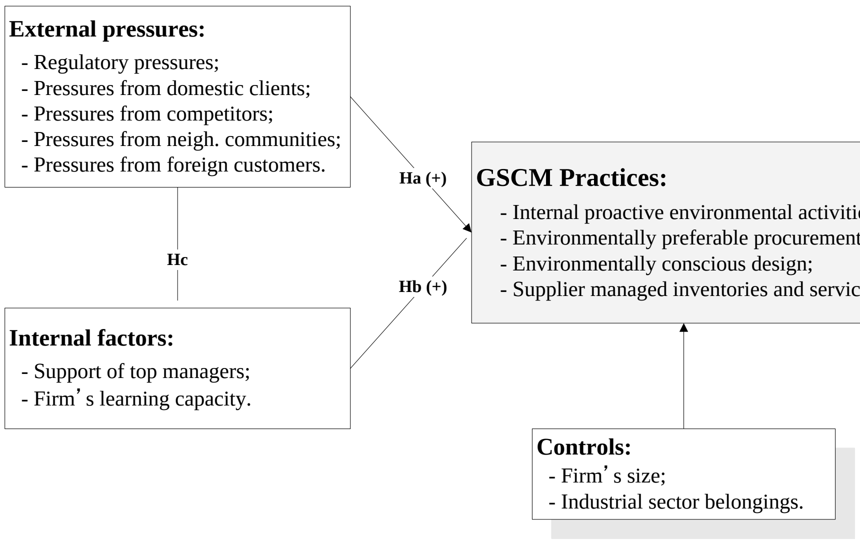


Fig.1: Overall analytical framework of questionnaire survey.

External pressures:

As explained above, the importance of external factors is borrowed to illustrate the complementary nature of the factors for Chinese companies to adopt GSCM practices at the early stage of environmental policy transformation. Besides the requirements of governmental regulations, the domestic and foreign clients, competitors and neighboring communities may exert pressures on the companies (Hall, 2000). These external pressures have jointly prompted the companies to become more aware of their environmental problems and to practice certain GSCM activities (Sarkis, 1998; Hervani et al., 2005). According to Zhu and Sarkis (2006), Hall (2000) and Sarkis (1998), external pressures are believed to be the important factors affecting a firm's GSCM practices.

Internal factors:

As is well known, the institutional theory neglects certain fundamental issues of business strategy. It is argued that the firms adopt heterogeneous sets of environmental practices also due to their individual interpretations of the objective pressures from the outside. The difference between the 'objective' and 'perceived' pressures may lead to diverse responses from the firms. Therefore, the analytical model adds two internal organizational factors, namely support of top managers and a firm's learning capacity, to jointly explain a firm's GSCM practices. Top management support can affect new initiatives success by facilitating employee involvement or by promoting a cultural shift of the company, etc. As GSCM is a broad-based organizational endeavor, it has the potential to benefit from top management support. Meanwhile, a firm's learning capacity is viewed as especially important in a resource-based framework. GSCM practices are amenable to the benefits derived from learning since they are human resource-intensive and greatly rely on tacit skill development by employee involvement, team work and shared expertise (Hart, 1995). The capacity for implementing innovative environmental approaches is normally enhanced by employee self-learning, professional education and job training. The education level of employees and the frequency of internally environmental training are often used as proxies of a firm's learning capacity.

The linkage of external and internal factors:

As discussed above, the addition of internal factors reasonably complements the institutional theory and a firm's internal factors may be viewed as mediators to adjust the influences of outside pressures. A firm will be unlikely to implement GSCM activities if it does not have the necessary capacities no matter what pressures it faces.

2.2 Samples and data collection

The questionnaire survey was conducted in the region of the Yangtze River delta during April to May of 2009. Two small areas in the delta were selected for the survey implementation. One is Taichang, a county-level city in Jiangsu Province. Another is Kangqiao industrial park based in Shanghai. The questionnaire format consists of four major components: general information of the firms; GSCM activities such as environmentally preferable procurement; the degree of external pressures felt by the firms; and evaluations of environmental and economic performances. The environmental managers were chosen as focal points in the survey to answer the questions concerning GSCM issues in their companies. Over a period of approximate two months, the survey was conducted in two phases. At the first stage, local government officials, and seven companies were communicated in order to test the validation and answering feasibility of the survey document. The finalized format was sent to 210 enterprises on a name list provided by the local environmental protection bureaus (EPBs). A total of 165 respondents were confirmed to be useful for the analysis, meaning a relatively high 78.6% of valid response rate due to the coordination of local EPBs. The distribution of usable respondents by industrial sectors is listed in Table 1. As expected, the samples from the sectors of machinery manufacturing, chemicals and textile and dyeing account for nearly half of the total, which are the representative industries in the study area.

Table 1: Distribution of the usable respondents by industrial sectors

Sector	Number of samples	Percentage
Paper	5	3.0
Textile and dyeing	19	11.5
Chemicals	24	14.6
Plastics and rubber	7	4.3
Metals	5	3.0
Machinery and equipment manufacturing	35	21.2
Electronics	6	3.6
Automobile	13	7.9
Printing	3	1.8
Construction	5	3.0
Others	43	26.1
In total	165	100.0

2.3 Operationalization of the variables

Dependent variable:

The dependent variable in the analytical framework is overall level of GSCM (L_{GSCM}). A firm's L_{GSCM} may be presented by a series of practical activities since it is difficult to directly measure the degree of GSCM involvement. Twelve items of GSCM activities were identified to estimate a firm's overall level of GSCM practices in current Chinese context, as listed in Panel A of Table 2 and abbreviated as GA1 to GA12. The firms were requested to present a five-point Likert scale to each item of the twelve activities. The scales are defined as: 1 = not considering the activity at all; 2 = planning to consider; 3 = considering currently; 4 = partially implementing; and 5 = implementing successfully. The average score of all the twelve items was used to represent the firm's L_{GSCM}. In a similar way, the average score of the items of each GSCM category was used as the level of practice of that category.

Independent variables:

The determinant factors for firms to adopt GSCM activities include external pressures and internal factors. As listed in Panel B of Table 2, five external pressures and three internal factors are classified. In a similar way, a five-point Likert scale was used to measure the importance, strength or degree of each factor: 1 = not at all; 2 = to some degree; 3 = moderate; 4 = relatively high; and, 5 = very high. The score of each factor was used to estimate their relationships with L_{GSCM}. An only exception is for FCLIENT (pressure from foreign customers). The firm's export ratios were used as the proxy for this variable. It is assumed that the higher a firm's export ratio was, the higher pressure from foreign markets would be felt by the firm. The export ratios were classified into four levels in the questionnaire format with consideration of easier responses from the surveyed firms.

Control variables:

Two more variables are introduced into the analytical framework as the controls. One is company size and another is industrial sector belongings. Panel C of Table 2 lists the valuation methods of control variables. A natural log of the turnover in 2008 was used to represent a firm's size. A firm's industrial sector affiliation is classified into two types, with '1' referring to environmentally sensitive industries (ESI) and '0' being the non-ESI. ESI in China include mining, thermal power, construction materials, pulp & paper products, metallurgy, petroleum, brewery, ferment, textiles, pharmacy, tanning and chemical industries (SEPA, 2003). The others are classified as non-ESI.

Table 2: Definition and valuation of GSCM activities, the determinant factors and the controls

Variable		**Description of the proxy**	**Valuation**					
			0	**1**	**2**	**3**	**4**	**5**
Panel A: GSCM activities								
L_{GSCM}	Internal proactive environmental management (C1)	Achieving ISO14001 certification (GA1)						
		Cleaner production auditing (GA2)						
		Reutilization of byproducts and other wastes (GA3)						
	Environmentally preferable procurement (C2)	Require the suppliers to offer cleaner products (GA4)						
		Evaluate environmental performances of suppliers (GA5)						
		Provide education & technical assistance for suppliers (GA6)						
		Environmental education for internal purchasing staffs (GA7)						
	Environmentally conscious design (C3)	Work closely with suppliers in product design (GA8)						
		Work with suppliers on waste minimization (GA9)						
		Provide environmental information of products (GA10)						
	Supplier managed inventories (C4)	Entrust suppliers to manage some of inventories (GA11)						
		Offer inventory management services for clients (GA12)						
Panel B: Determinant factors								
External pressures	REGULATORY	Pressure of environmental regulations						
	DCLIENT	Importance of domestic client's environmental expectation						
	COMPETITOR	Importance of competitors' green strategies						
	COMMUNITY	Pressure of complaints of neighboring communities						
	FCLIENT	Pressure of foreign customer's environmental expectation						
Internal factors	TSUPPORT	Degree of support from firm's top managers						
	EDUCATION	Education level of the employees						
	TRAINING	Frequency of internally environmental training						
Panel C: Control variables								
Characteristics of the firms		Firm's size (LSIZ)	Natural log of firm's turnover					
		Industrial sector belongings (SECTOR)						

2.4 Results of the questionnaire survey and analysis

2.4.1 GSCM practices of the firms

Table 3 gives a statistical summary of scores of the defined GSCM activities. In general, it can be concluded that Chinese companies are still at a very preliminary stage for GSCM practices.

The surveyed firms have started to implement internally proactive CEM to some degree. Most of them plan to think about or are considering the environmental activities which would be jointly practiced with external actors on the supply chain. Slight improvement was observed in this study if compared with a previous survey conducted in north China by Zhu and Sarkis (2006). This change may be attributed to the different location of the study areas. As described earlier, the region for this study has a relatively developed economy, and the firms there may be performing better on the environment than those in other areas.

Table 3: Statistical summary of GSCM activities of the surveyed firms

Categories and items of GSCM activities	Obs.	Mean	Std. dev.	Min.	Max.
Internal proactive environmental activities (C1)	158	3.60	1.07	1	5
GA1	159	3.41	1.49	1	5
GA2	160	3.51	1.35	1	5
GA3	160	3.93	1.14	1	5
Environmentally preferable procurement (C2)	159	3.38	1.01	1	5
GA4	160	3.84	1.16	1	5
GA5	159	3.47	1.19	1	5
GA6	160	2.76	1.27	1	5
GA7	162	3.48	1.27	1	5
Environmentally conscious design (C3)	153	3.32	1.04	1	5
GA8	159	2.93	1.30	1	5
GA9	159	3.45	1.22	1	5
GA10	156	3.54	1.27	1	5
Supplier managed inventories and services (C4)	157	3.11	1.23	1	5
GA11	158	3.10	1.24	1	5
GA12	158	3.12	1.33	1	5
Overall level of GSCM practices (L_{GSCM})	148	3.39	0.91	1	5

The surveyed firms react differently to the classified GSCM activities. Figure 2 provides details of the score distribution of GCSM activities practiced by the respondents. Many firms are implementing certain proactive internal CEM practices. Nearly 70% of the surveyed firms are reutilizing byproducts and other generated wastes at some degree. Around half of them are making efforts to achieve ISO14001 certification and are pursuing cleaner production audit. The firms are selective to those GSCM activities requiring cooperation with external actors on the supply chain. About 70% of the respondents are asking their upstream suppliers to provide cleaner materials or products to avoid possible environmental risks. The ratio of firms, which arrange internally environmental education for their procurement staffs and work closely with their suppliers for waste minimization, also reaches around 50%. Another item of GSCM activity practiced relatively better by the firms is to provide product-related environmental information for the clients. However, most of the firms do not supply technical assistance to their suppliers. About 65% of the firms have not taken any action for environmentally conscious design together with the suppliers. In summary, the surveyed firms' GSCM activities are obviously due to individual business needs and benefits from their own perspectives. GSCM is still a new concept for most Chinese companies. More time is needed for them to recognize the importance of strategic cooperation with the other members on the supply chain. In-depth GSCM practices within a wider scope would be adopted if firms could unite as a group with a shared strategy on business and environment issues.

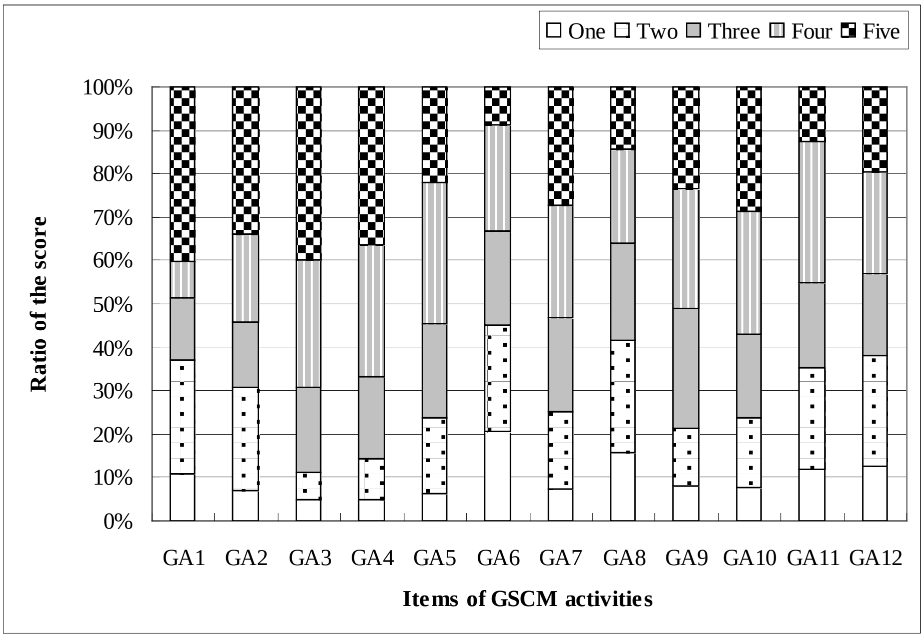


Fig.2: Distribution of the scores of firm's GSCM activities.

2.4.2 Descriptive statistics of the other variables

Table 4 summarizes the variables describing the determinant factors of GSCM activities. Firms gave higher scores to the pressures from external stakeholders. Among the external pressures, the regulative requirements and domestic client's environmental expectations are viewed as highly important, which achieves an average of 4.41 and 4.29 respectively. Keeping up with competitors in the same sector is also regarded as an important factor (averaging at 4.08). The sampled firms usually carry out internal environmental training at a frequency of 2 or 3 times a year. The education level of employees is relatively low probably because most of the firms belong to traditionally labor-intensive industries. An average score of 2.87 is presented to top manager's support, which implies that the firm's managers do not care much about GSCM efforts. This finding shows a fact that the managers of Chinese companies are not seriously considering environmental activities out of basic compliance.

Table 4: Statistical summary of the determinant factors

Variables and abbreviations		Obs.	Mean	Std. dev.	Min.	Max.
External pressures	REGULATORY	156	4.41	0.75	1	5
	DCLIENT	156	4.29	0.86	1	5
	COMPETITOR	152	4.08	0.85	1	5
	COMMUNITY	162	3.88	1.73	1	5
	FCLIENT	150	2.46	1.27	1	4
Internal factors	TSUPPORT	159	2.87	1.35	1	5
	EDUCATION	160	3.30	1.03	1	5
	TRAINING	159	4.15	0.75	1	5

Regarding the control variables indicating company characteristics, most of the samples are small and medium-sized. Large companies, with an annual turnover of more than CNY 300 million (CNY: Chinese currency Yuan), only account for 7.4% of the total. Small enterprises, which have less than 300 employees or yearly sales of less than CNY 30 million, have a share of 64.2%. The remaining 28.4% is medium-sized companies. According to the classification criteria of Chinese national environmental authority, half of the samples are categorized as ESI (49.1%). The other half is non-ESI. Most of the respondents (71.4%) process raw materials or produce components for downstream manufacturers.

2.4.3 The relationship between L_{GSCM} and the determinant factors

Standard multiple regressions were performed with L_{GSCM} as the dependent variable and each of the determinant factors and controls as independent variables. The results are listed in Table 5.

Among the external pressures, DCLIENT and COMPETITOR are significantly and positively associated with L_{GSCM} at p=0.000. This implies that domestic clients' environmental preferences and competitors' green strategies for differentiation are major external drivers for firms to adopt GSCM activities. One more external factor which has slightly positive correlation with L_{GSCM}, significant at p<0.01, is REGULATORY. Government regulations were believed to be dominated forces for CEM in the past since a firm's environmental strategies are imposed coercively via environmental sanctions (Delmas, 2002). However, this study classified GSCM practices as those beyond of basically environmental compliances. The governmental requirements may become relatively minor factor for the adoption of GSCM practices. No significant associations are found between the other two external pressures, COMMUNITY and FCLIENT, and L_{GSCM}. The surveyed companies highly valued the pressure from their neighboring communities. However, community pressure cannot account for a firm's GSCM efforts probably because the communities mainly complain the environmental illegal cases of companies rather than require proactive efforts such as GSCM practices. The pressure from foreign clients is not strongly felt by manufacturers in the current phase.

Regarding the internal factors, the support of top managers is not found to be significantly associated with a firm's L_{GSCM} in this survey, which is in contrast with the result of Carter et al. (1998). Nevertheless, the two variables representing a firm's learning capacity, education level of employees (EDUCATION) and frequency of internal environmental training (TRAINING), are significantly and positively associated with L_{GSCM} at p=0.000. This result is identical with Zhu et al. (2008), which confirm a hypothesis that the extent of GSCM practice engaged in by Chinese companies is positively related to the level of organizational learning capacity.

Table 5: Regression results for L_{GSCM} and each of the determinant factors

Variables entered	Coefficient	t-Statistic	P-Value	Variables entered	Coefficient	t-Statistic	P-Value
a) REGULATORY				***b) DCLIENT***			
β_0	0.497	0.851	0.397	β_0	0.439	0.896	0.372
REGULATORY	0.266	2.760	0.007	DCLIENT	0.342	3.890	0.000
LSIZ	0.176	4.856	0.000	LSIZ	0.147	4.172	0.000
SECTOR	0.293	1.960	0.052	SECTOR	0.322	2.210	0.029
F-Value		9.673		F-Value		12.583	
R^2 (adjusted)		0.169		R^2 (adjusted)		0.214	
c) COMPETITOR				***d) COMMUNITY***			
β_0	0.409	0.859	0.392	β_0	1.507	3.117	0.002
COMPETITOR	0.356	4.224	0.000	COMMUNITY	0.041	0.840	0.402
LSIZ	0.155	4.457	0.000	LSIZ	0.177	4.452	0.000
SECTOR	0.258	1.772	0.079	SECTOR	0.260	1.680	0.095
F-Value		13.382		F-Value		7.112	
R^2 (adjusted)		0.226		R^2 (adjusted)		0.123	
e) FCLIENT				***f) TSUPPORT***			
β_0	1.804	4.026	0.000	β_0	1.803	4.695	0.000
FCLIENT	0.033	0.544	0.588	TSUPPORT	-0.021	-0.341	0.734
LSIZ	0.156	3.959	0.000	LSIZ	0.167	4.018	0.000
SECTOR	0.253	1.573	0.118	SECTOR	0.278	1.765	0.080
F-Value		5.281		F-Value		6.188	
R^2 (adjusted)		0.097		R^2 (adjusted)		0.109	
g) EDUCATION				***h) TRAINING***			
β_0	0.708	1.846	0.067	β_0	-0.310	-0.726	0.469
EDUCATION	0.374	5.721	0.000	TRAINING	0.597	7.001	0.000
LSIZ	0.151	4.592	0.000	LSIZ	0.128	4.031	0.000
SECTOR	0.178	1.299	0.196	SECTOR	0.126	0.955	0.342
F-Value		18.884		F-Value		26.249	
R^2 (adjusted)		0.294		R^2 (adjusted)		0.370	

3. Case studies identifying the effectiveness and opportunities of GSCM practices

3.1 Focal companies for case studies

Three companies were selected for case analysis, namely Shanghai GKN Drive Shaft Co., Ltd., Taicang Zhenhui Chemical Fiber Co., Ltd., Nine Dragons Paper Industries (Taicang) Co., Ltd., which are abbreviated as SDS, Zhenhui and Nine Dragons respectively. SDS is a manufacturer of automotive components based in Shanghai Kangqiao Industrial Park. Zhenhui is a chemical fiber company and Nine Dragon is a paper making plant, with both situated in Taicang City of Jiangsu Province. The background data of the three companies is listed in Table 6.

Table 6: Background information of the three target companies

Information item	SDS	Zhenhui	Nine Dragon
Time of establishment	May, 1988	July, 2002	April, 2002
Location	Shanghai Kangqiao Industrial Park	Taichang city, Jiangsu Province	Taichang city, Jiangsu Province
Ownership	Joint venture	Private, domestic	Private, fully foreign funded
Number of employees	1,747	1,100	2,200
Major products	Auto constant velocity sideshafts (CVS), propshafts and others	Polyester chips, polyester pre-oriented yarn (POY), polyester fully drawn yarn (FDY), polyester DTY, etc.	Corrugated paper, corrugated cardboard and kraft linerboard
Production capacity in 2008	4 million pieces of CVS and 0.6 million propshafts	30,000 tons of polyester chips, 140,000 tons of POY& FDY	3 million tons of corrugated paper
Annual sales	2.1 billion CNY (2008)	1.85 billion CNY (2008)	3.3 billion CNY (2007)

3.2 Major supply chain relationships of target companies

3.2.1 Major supply chain relationships of SDS

Major supply chain relationships of SDS are depicted in Fig.3. Raw and supplemental materials of SDS mainly come from the domestic suppliers. As examples, different types of steel are bought from Shanghai Fifth Steel Works of Baosteel Group. Whereas, lubricating oil and grease are imported from Germany. The cooperation parts purchased by SDS mainly include different types of besides-star wheel from Shanghai Automotive Forging Factory, dust cap from the 1st Branch Factory of Hualing Mechanical Works, different types of clamps from Oetiker Industries Tianjin Ltd., steel ball from Shanghai Bearing Works, etc. Products of SDS are CVS, propshafts, industrial shaft, universal joint drive shaft assembly and other automotive components. Downstream customers are major domestic car makers including Shanghai-Volkswagen (SVW), SGM, FAW-Volkswagen (FAW-VW), Chery, Dongfeng Honda, Nissan, B-BMW, BJC, HN-Mazda and Guangzhou Honda. SDS's main customers, SVW, FAW-VW and SGM, have a large share of domestic car market in China. These automobile makers have already practiced strict management on the design, manufacturing, parts supply, sales service process, with relatively mature GSCM practice on new product development, manufacturing and materials management, pollution control, and energy saving.

3.2.2 Major supply chain relationships of Zhenhui

Main supply chain relationship of Zhenhui is described in Fig.4. Major raw and supplemental materials include purified terephthalic acid (PTA), ethylene glycol (EG), and the major accessories include JN-D301 POY oil, JN-D202 FDY oil, TiO_2, antimony triacetate (catalyst), liquid heat medium and so on. The raw material PTA is mainly imported from multinational companies and domestic supplier as Ningbo Mitsubishi. The products of Zhenhui are various types of polyester chips, polyester pre-oriented yarn (POY), low elastic polyester filament (DTY), polyester fully drawn yarn (FDY). Most of the clients are small and medium enterprises and a third party is responsible for logistics between the company and the dock.

3.2.3 Major supply chain relationships of Nine Dragons

As described in Fig.5, the main raw materials of Nine Dragons are imported waste paper and unbleached softwood pulp, 70% of them are from Europe and the U.S., Japan, the rest 30% are from the East of China. The main foreign supplier of raw materials is the America Chung Nam, Inc., which is the parent company of Nine Dragons. The main domestic supplier is Jiangsu Renewable Resources Co., Ltd. The supplemental materials purchased by the company are dispersed rosin size, chemical additives for papermaking, industrial oxidized starch, polyster wire mesh, blankets, dry nets, etc. The company’s major products are 126-250 g/m^2 corrugated cardboard and kraft linerboard. Products of Nine Dragons are all for domestic market. Its customers are mainly located in eastern China as well as Hubei, Shandong and other areas of China. Moreover, the fixed customers account for 80%, and its indirect customers are mainly home electronic appliance companies, such as Asus, Foxconn and Samsung, etc.

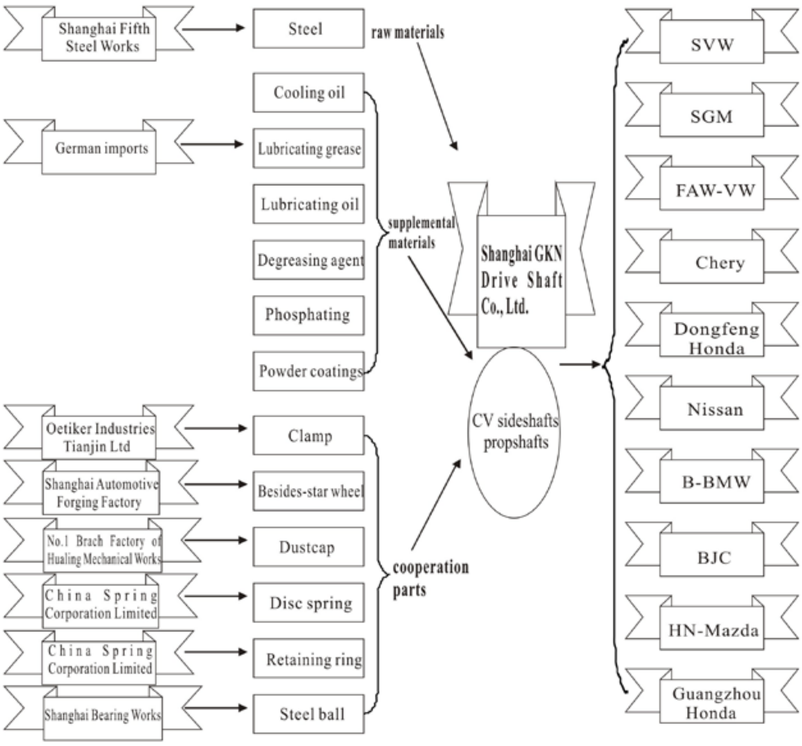


Fig.3: Main supply chain relationships of SDS.

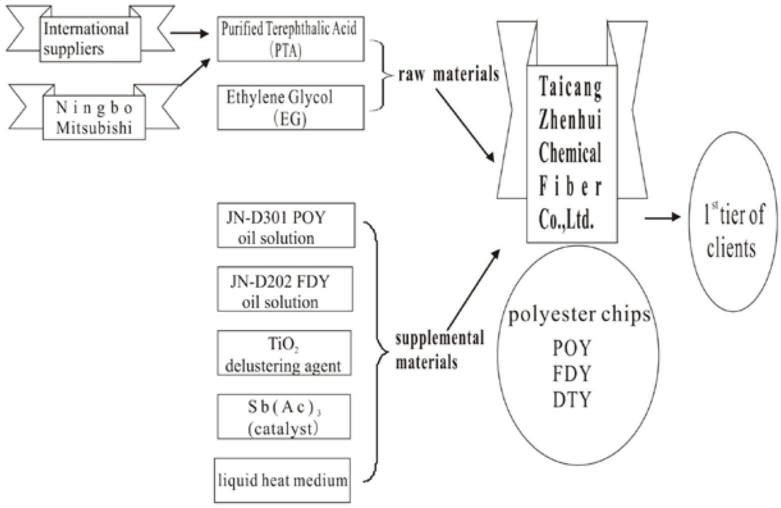


Fig.4: Main supply chain relationships of Zhenhui.

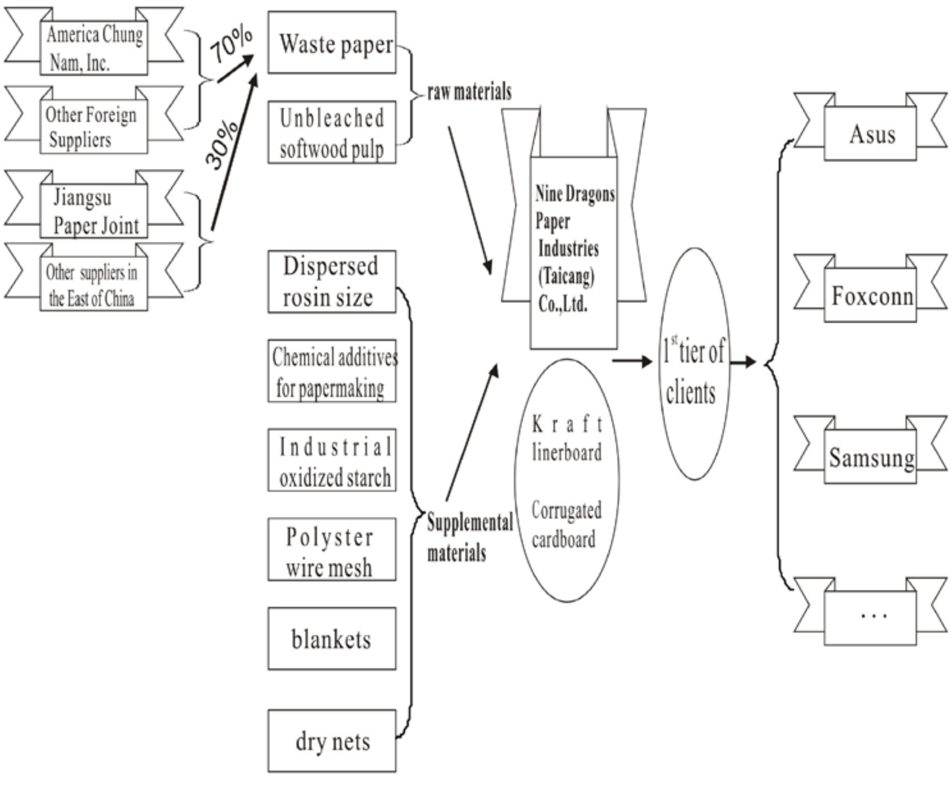


Fig.5: Main supply chain relationships of Nine Dragons.

3.3 Practices, effectiveness and opportunities of GSCM of target companies

3.3.1 The case of SDS

3.3.1.1 GSCM practices of SDS and their effects

After the establishment in 1988, SDS has carried out variously internal proactive environmental management. SDS passed ISO14001 certification in 2001 and set up a department to take responsibility of the company's environmental management in 2002. The company conducted several environmental impact assessments for the replenishment projects with aims to increase the production capacity. In 2004, SDS set up a leading group on environment, safety and occupational health with a full-time engineer and a few part-time environmental staffs.

Two initiatives stand out as typical GSCM practices of SDS in recent years. One is the "SAIC-35% Energy Saving Plan" launched by its holding company, Shanghai Automotive Industry Corporation (SAIC). Another is the "SGM-Greening the Supply Chain Project" implemented by a major client, Shanghai General Motors (SGM). In a strict sense, the former is an internal activity enhancing resource efficiency of the group. On August 5, 2007, SAIC issued the goal of energy saving, to reduce the comprehensive energy use per 10,000 CNY of output by 35% based on 2005 level by the end of 2010. Regarding the second initiative, SGM launched the "SGM-Greening the Supply Chain Project" in January of 2008. SDS followed the energy saving plan of SAIC and formally participated in the GSCM project of SCM by taking the following actions.

Energy saving activities based on "SAIC-35% Energy Saving Plan"

The energy saving efforts of SDS can be divided into two stages. The first phase is up to 2007 and mainly includes occasional energy saving activities. Since 2008, external pressures propelled the company to create a detailed energy saving plan. The efforts for energy saving under "SAIC-35% Energy Saving Plan" are listed in Table 7. The activities include managerial measures and technological upgrading. During January to May of 2009, SDS put forward 48 initiatives on energy saving, among which 43 (around 90%) have been completed to satisfy the goal of energy saving set by SAIC. As SDS has to invest in new energy-efficient equipments and processes, it needs to train the employees to establish adequate capacity for the implementation of energy saving plan. All such activities have cost SDS a great deal. Meanwhile, the energy saving programs saved money in terms of reducing the cost of electricity and raw materials and waste disposal expenses. As energy saving and emission reduction are current focus of environmental policy of central and local governments, better environmental performance earns more credit and subsidies from the government.

As the Chinese shareholder, SAIC performs a role of monitoring energy saving efforts of SDS. For instance, SDS is required to keep in pace with the environmental policies of the head corporation and to report its comprehensive energy use. In 2008, SAIC delivered experts to properly train SDS employees on energy management. Table 8 exhibits the achievements of energy saving efforts of SDS. Based on the fixed price of 2005, the comprehensive energy use per 10,000 CNY of output has declined by 13.9%, 27.7% and 28.9% in 2006, 2007 and 2008, respectively, if comparing with that of 2005.

Table 7: Approach, focus and activities of energy saving of SDS during 2008 to June of 2009

Approach	Focus	Activities
Managerial measure	Establishment of energy saving institution and plans, training and education	◈ Establishment of energy management team with senior executives in charge; ◈ Three levels of energy management network: company, factory and workshop; ◈ Amendment of company's "Resource and Energy Management Procedure", establishment of energy management files based on ISO14001; ◈ Qualification certificate is required for energy management members, regular training of the management team; ◈ Training of related staffs by SAIC, Shanghai Energy Monitor Center and Shanghai Energy Conservation Center in 2008; ◈ Electromechanical energy saving training of related workers in 2009; ◈ Monthly check of energy saving and emission reduction; ◈ Monthly meeting on energy saving, announcement of results of the monthly check, setting up of monthly energy initiatives.
Structural modification	Adjustment of equipment, product and energy structure	◈ Restructuring energy use, phase-out of low-efficient coal-boiler and phase-in of high-efficient oil-fired boiler; ◈ Replacement of precision forging equipment instead of hot forging equipment; ◈ Rational arrangement of production in the second half of 2008 during the market recession in order to improve energy efficiency.
Technological upgrading	Identification and implementation of feasible projects	◈ Adjustment of fan controller in the cooling tower. The fans are operated based on water temperature instead of keeping continuous running; ◈ Improvement of continuous carburizing furnace; ◈ Improvement of air-cooling control; ◈ Improvement of flow gate control, updating and shut down of automatic flow gate and hoister; ◈ Residual heat reuse of air compressor by heating the washing water through heat exchanger, subsequently cooling down by fans; ◈ Upgrading the coal-boiler by oil-fired boiler; ◈ Upgrading electricity meters, reuse of reclaimed water.

Table 8: Comprehensive energy use of SDS (with fixed price of 2005)

	2005	2006	2007	2008	2010
Output value (10,000 CNY)	132,616	184,228	243,296	230,479	--
Comprehensive energy use (tce)	25,831	30,914	34,272	31,922	--
Energy use per 10,000 CNY output	0.195	0.168	0.141	0.139	--
Goal of energy use per 10,000 CNY output	0.2	0.175	0.151	0.127	0.127
Growth rate of output value	--	38.9%	83.5%	73.8%	--
Growth rate of energy use	--	19.7%	32.7%	23.6%	--
Decline rate of energy use per 10,000 CNY output	--	13.9%	27.7%	28.9%	35%

From the beginning of 2008, SDS outlined specific plans for further energy saving in responding to the "SAIC-35% Energy Saving Plan". A new round of better becoming performance can be observed in the first half of 2009. Table 9 shows the changes. During January to May, 2009, the company total energy use indicated a decrease of 7.8%, and the energy use for producing per set of CVS decreased by 4.1%.

Table 9: The change of energy performance of SDS in the first half of 2009

Indicator	January-May 2008	January-May 2009	Decrease rate (%)
Energy use (tce)	7,468	6,886	7.8
Output of CVS (in 10,000)	220.5	212.1	3.8
Average energy use (tce/10,000 CVS)	33.9	32.5	4.1

Activities involving in "SGM - Greening the Supply Chain Project"

SDS participated in "SGM - Greening the Supply Chain Project" as an important supplier of SCM. The detailed activities and corresponding achievements in 2008 are listed in Table 10. Main GSCM practices cooperated by SDS include: participation in environmental training of the suppliers provided by SGM experts; preparation of an action plan for GSCM practices; review of the plan and onsite guidance to the suppliers by SGM experts; implementation of the examined plans by SDS; implementation information sharing by SDS; and, performance evaluation and feed back by SGM. In 2008, SDS implemented three action plans: water balance, energy audits and saponification in stead of spraying oil before cold sizing to reach zero emission of washing liquid. While the total investment of the three actions was 0.41million CNY, its gross benefit was 0.7135 million CNY due to the energy efficiency improvement, water saving as well as waste reduction. Therefore, SDS got 0.3035 million CNY net profit. Meanwhile, the environmental benefit was significant, including a reduction of 904.4 tons CO_2 emissions, 50.1 thousands tons of wastewater, 12 tons solid waste, and a saving of 562,417 kWh electricity, 19 tons coal and 50,100 tons water annually.

3.3.1.2 Further GSCM opportunities of SDS

GSCM practices of SDS shall be improved further, particularly in internally proactive environmental management, the collaboration with various suppliers for developing environment-friendly products and improving management as a whole. The GSCM activities to be implemented further include: implementation of cleaner production audit; to reclaim the metal, wooden and cardboard boxes and other containers; to reclaim the byproducts; and, to collaborate with the suppliers to purchase the environment-friendly products.

Although SDS is not on the list of compulsive cleaner production audit, it still has potential to save energy and reduce emissions. Implementation of cleaner production audit can help the company carry out environmental management systemically. Currently, the containers for transporting the products of SDS are all for single use and the reclaiming system has not yet been established. Since the containers have high angular rigidity and are hard to deform, reuse of them is possible. The company could collaborate with their clients for reclaiming these containers and reusing them. The main product of SDS is automotive transmission shaft which is made from steel. The byproducts like scraps and used products can be recycled as rolled steel. SDS should collaborate with the downstream car assembler in recycling the vehicle parts and reuse them for reproduction. In addition, SDS is the terminal clients of many lubricants and parts makers. From this viewpoint, SDS could collaborate with the relevant suppliers and play its influence like requiring green products from the suppliers, setting standards and evaluating environmental behaviors of suppliers, providing environmental training or technical assistance for suppliers, etc.

Table 10: The practices of SDS involving in "SGM Green Supply Chain Project"

Project No.		1	2	3	In total
Content	Action plan	Water balance project of Zhoupu plant	Energy audit	Saponification in stead of spraying oil before cold sizing	
	Action content	Searching water saving potentials in the plant	Increasing processing ability of CC inside wheel in P6 furnace	Saponification in stead of spraying oil before cold sizing	
Implementation	Department on duty	Planning department	Heat treatment workshop	Forging workshop	
	Start time	April, 2008	May, 2008	May, 2008	
	Finish time	September, 2008	September, 2008	December, 2008	
Economical performance	Investment (CNY)	60,000	0	350,000	410,000
	Raw materials saving (CNY/year)	--	--	170,000	170,000
	Energy saving (CNY/year)	--	330,000	21,280	351,280
	Water saving (CNY/year)	127,215	--	1,542	128,757
	Waste charge saving (CNY/year)	51,480	--	12,000	63,480
	Total saving (CNY/year)	178,695	330,000	204,822	713,517
	Investment recovery period (year)	4 months	--	16 months	--
Environmental performance	CO_2 reduction (ton/year)	--	562.4	342	904.4
	Energy saving	--	562,417 kWh/year	19 tons coal per year	--
	Water saving (ton/year)	49,500	--	600	50,100
	Solid waste reduction (ton/year)	--	--	--	12
	Waste liquid mitigation (ton/year)	49,500	--	600	50,100

3.3.2 The case study of Zhenhui

3.3.2.1 Internal GSCM practices of Zhenhui and their effects

In December 2004, Zhenhui established its environmental management system by setting up a leading group with the company manager as the head of group, and assigning a few environmental protection staffs. Zhenhui passed ISO14001 certification in 2006. GSCM practices of Zhenhui focused on internally proactive environmental management activities like cleaner production audit and energy audit.

In April 2007, Zhenhui started its work of cleaner production audit. In September, 2007, "Cleaner Production Audit Report of Zhenhui" was finalized. In the same year, Zhenhui carried out several technological upgrading projects, including renewal of boiler auxiliary equipment, air compressor modification of elasticizing plant and reuse of the reclaimed water. The detailed activities of Zhenhui during cleaner production audit are listed in Table 11.

In March, 2008, Zhenhui finished its report of energy audit and proposed several energy saving advices such as introduction of circulating pump and modification of air compressor. In November 2009, Zhenhui applied as a pilot company of developing circular economy initiated by local government. The contents of energy audit are listed in Table 12, which include energy management and consumption status, energy consumption structure, energy measurement and statistics, etc. The significant part is the audit on energy management status, potential analysis of energy saving and technological upgrading proposals.

There are 5 major technological reconstruction projects for energy saving and emission reduction in Zhenhui. The first one is to reuse the reclaimed water. This project uses the domestically advanced wastewater treatment equipment, which is the first water reclamation equipment in domestic textile industry. Water reused per day is 600 m^3, which can save 504,900 CNY of water fee and 50.91 tce energy. This project started in January and ended in July of 2007. The total investment was about 609,000 CNY. The second project is to reuse the exhaust gases. The advanced and packed stripping tower was adopted. The residual gas is sent to be burned in the coal stove, which reduces air pollutant emissions and saves energy. The third one is to reuse residual heat. This project applied the refrigeration technology in which atmospheric steam is utilized as the heat source. As a result, the operational cost decreased. The rest are two electricity-saving projects. One is to upgrade the air compressors to be frequency convertible. According to the demand of different plants, two air compressors and related pipe system were added. This can save 1.0512 million kWh electricity, equivalent to 378.43 tce, and 0.5359 million CNY of charge. The total investment was 1 million CNY. Another is to optimize the pump system by using the high efficient pump to replace the pump with surplus capacity. Automatic control system was also installed.

Zhenhui achieved good economic and environmental performances by the end of 2008 due to above mentioned internally proactive environmental efforts, which are shown in Table 13. Zhenhui is a chemical fiber producer consuming large amount of energy and generating heavy pollutions. Due to the cleaner production audit in 2007, Zhenhui achieved at least 9.4373 million CNY economic benefits from the consumption reduction of water, electricity, coal, raw materials and the decrease of wastewater discharge and waste silk. Due to the technological upgrading projects, Zhenhui saves 965.89 tce energy, 0.198 million m^3 of water, and 4.5005 million CNY of cost per year. The comprehensive energy use per unit of industrial added value appeared a sharp decline during 2005-2007 but then a slight increase in 2008. As for the emission indicators, they are stable during 2005 to 2007, and an obvious improvement in 2007-2008. The emission of COD and wastewater exceeding emission standard were typical indicators. Before 2008, the wastewater discharge amount exceeding emission standard was 0.215 million tons, while this data decreased to 0.0135 million tons in 2008 due to the construction of new water purification facility. The emission of SO_2 also experienced a sharp decrease.

Table 11: Cleaner production activities and their effects of Zhenhui

Time	April-July, 2007
Contents and procedures	***Planning and Organization*****:** Zhenhui established a team for cleaner production in May, prepared the audit plan and arranged training by inviting external experts. ***Pre-Assessment to find cleaner production potentials:*** Define filament process as audit focus; formulate cleaner production objectives and measures; encourage the employees to propose reasonable suggestions, as a result, more than 100 advices were collected and 32 programs were created. ***Assessment:*** Material flow analysis and identification of waste sources. ***Programs screening:*** 20 feasible programs with no or low-cost and 3 medium or high-cost programs were selected. ***Program implementation:*** Allocation of funding and implementation department; assessment of implementation effect. ***Continued cleaner production:*** Establishment of organization; keeping cleaner production working group; incorporating cleaner production management into daily management, establishing incentives; making sustainable cleaner production plan. ***Experience:*** Education and training the staff is the premise, leader's support is the guarantee; staff's involvement is the base; field works is essential; cleaner production audit can improve the level of environmental management dramatically.
Specific programs	***20 low-cost programs***: Like substituting cooling water by desalinated water; construction of sealing walls for coal storage space; waste separation and recovery and so on. ***2 medium-cost programs:*** Replenishment of air blower in spinning plant; substituting linisher component by sand cup. ***1 high-cost program:*** Reuse of the reclaimed water.
Effects	Based on an incomplete statistics, the value from coal, energy, material and water saving, and reduction of wastewater and solid waste reached 9.4373 million CNY in 2007. From January to August 2007, the wastewater discharge was 108,300 tons, declined by 42.57% when comparing with the same period of 2006. Since July 12, 2008, the daily sewage discharge reduced to 13 tons and COD concentration was 14mg/L with a great decrease from 30mg/L in previous year. Waste silk per ton of product was 8.79Kg, which is better than the level 3 in Cleaner Production Technical Guideline of fiber industry.

Table 12: Energy audit results of Zhenhui

Energy management institution	Current situation	The leading group of energy management consists of the general manager, the deputy general manager and department leaders. Daily working team is founded under the leading group. The part-time energy managers are equipped from the top to down. Personal responsibility of energy management is also clarified.
Energy management system	Current situation	An energy management system has been made, including "Energy procurement and approval system", "Energy management standards", "Energy management system of measuring instruments", "Energy measurement and statistical management system", "Electricity conservation regulation" and "Assessment methods of raw, supplementary materials and energy use", etc.
	Problems	Further improvement is needed.
	Suggestions	With the increasing concern from the government, the company should collect new regulations and modify its related management system.
Energy measurement	Current situation	The total energy input and output measuring instruments are 100% equipped; the rate of meters for sub energy using equipments is 77.5%, and the average rate is 22%.
	Problems	The rate of measuring instruments for the second and third level energy using equipments is low. The company is lack of measuring instrument for the use of coal, steam and large electric facilities, which makes the detailed data collection to be difficult.
	Suggestions	The existing measuring instruments should be managed based on "Equipment and general management rule of measuring instruments for energy using unit", The files of measuring instrument shall be established.
Energy statistics management	Current situation	The energy consumption is reported by each sectors, the financial department counts the energy purchase, use and inventory quarterly and regularly sends the data to parent company and local statistics agency.
Energy quota management	Current situation	"Assessment methods of raw, supplementary materials and energy use 2007"and "Quota assessment in elasticizer department 2007" was formulated.
	Problems	Assessment items and basic data are not accurate and complete.
	Suggestions	To equip with measuring instruments and improve the monitoring methods; to specify the indicators for products, main processes and equipments.
Technological progress of energy saving	Current situation	Several technological improvements have been made in 2007, including application of frequency convertor, reasonable choice of air pressure for elasticizing, etc. The total investment is 9.399 million CNY. They can save 965.89 tce, 0.198 million m^3 water, and 4.5005 million CNY of cost annually.
Education of energy saving	Current situation	"Staff education and training system" was set up; energy saving education is promoted; the newsletter is utilized to promote publicity and awareness; advanced departments and individuals are awarded.
Summary		The management institution and system have been established, but need further improvement. The measuring instruments of main facilities need to be equipped. Energy statistics shall be improved for better quota management.

Table 13: Energy use per 10,000 CNY of output of Zhenhui

Year	2005	2006	2007	2008
Sales revenue (million CNY)	1,156.87	1,667.96	2,022.86	1,849.56
Gross industrial output value (million CNY)	1,200.65	1,673.71	2,077.63	1,850.32
Comprehensive energy use (tce)	20,051	29,457	36,413	42,382
Comprehensive energy use per unit of gross industrial output value (tce/ million CNY)	16.7	17.6	17.5	22.9

3.3.2.2 Other GSCM activities of Zhenhui

Zhenhui constructed the elasticizer industrial park in its area which is equipped with 100 sets of high-speed elasticizer. Most of companies in this park are small household workshops which are downstream customers of Zhenhui. Zhenhui provided workshops, financial guarantees and even environmental service such as sewage collection and treatment for them. Certain degree of mutual symbiotic relationship is formulated between Zhenhui and these costumers. Environmental management activities of Zhenhui, which were carried out in recent years, may influence these small companies in the future.

3.3.2.3 Further GSCM opportunities in Zhenhui

The key environmental management activities that Zhenhui plans to accomplish in the next stage are further energy saving and emission reduction, which contains two aspects. One is to install energy measuring instruments in equipments with high energy use such as circulating pump, water pumps, air compressor, cooling tower blower, freezer etc., to strengthen the daily management for optimizing the operational processes. Another is to continue to identify energy saving potentials and implement the programs for energy saving.

The GSCM activities of Zhenhui as so far mainly focus on internal energy saving and emission reduction. This may be attributed to the characteristics of the company that it is a raw material manufacturer with relatively heavy pollution intensity. Since the downstream customers are small companies and rely on Zhenhui in capital, working place and infrastructure, they lack power in shaping the supply chain relationships. However, Zhenhui really implemented a series of internally environmental management activities since 2006 and has accumulated rich experiences. This is a good start of further GSCM practices jointly with its upstream suppliers and downstream customers. As examples, Zhenhui may require green products from the suppliers, set standards and evaluate environmental behaviors of suppliers, providing environmental trainings or technical assistance for suppliers, etc. Research & Development Center of Zhenhui is recognized as technology center of fiber industry of Jiangsu Province. In the future, this center can play active role in collaborating with suppliers and customers to develop green products.

3.3.3 The case of Nine Dragons

3.3.3.1 GSCM practices of Nine Dragons and their effects

Nine Dragons is a fully foreign-owned enterprise with high energy use and pollution intensity, which makes it sensitive to the change of macro environmental policy. Nine Dragons pursues to abide by national and local environmental regulations, industrial and environmental standards. Nine Dragons established the pollution control facilities from the beginning. The initial investment for environmental protection was $20 million, 12.7% of the total investment. By the end of 2007, its total environmental investment reached 300 million CNY. Now, the green area of the factory is up to 300,000 m^2. During 2003 to 2006, Nine Dragons passed ISO14001 certification, OHSAS (Occupation, Health and Security Administration System) certification and China Environmental Label certification. Along with the institutional framework being concerned, Nine Dragons established the Department of environmental protection and resource recycling, with 300 staffs leaded by the general and department managers. It also set up the Supervision and Management Council consisting of 6 members with duty of daily patrolling within the company. In addition, Nine Dragons addresses environmental trainings of employees and managers. There are three levels of internal environmental trainings: company level, workshop level and team level. The company level training targets all department managers and external specialists are invited as the trainers, usually once a quarter. The workshop level training is arranged by the Department of Environmental Protection and Resource Recycling, usually once a month. The team level training is frequently conducted for all the related workers. Nine Dragons constructs a standard library and updates the books and journals on environmental protection annually.

The GSCM efforts of Nine Dragons focus on internally proactive environmental management, mainly including technological upgrading for pollution control and energy audit. The environmental requirements in China are becoming stricter in recent years. In 2006, Nine Dragons were once put on the blacklist of implementing energy saving plan by Jiangsu Province. After that, the company made a series of efforts in improving its environmental management.

In March 2007, Nine Dragons invested 60 million CNY to reconstruct the wastewater treatment plant by using the efficient IC (Internal circulation) reactor imported from the Netherland, which can convert organic matters to granular sludge and methane gas by metabolism. The company also introduced a water reclamation system which can recycle 36,000 tons of water per day, and increase the ratio of water reuse up to 47%. Upon the completion of these reconstruction projects, the company treated 1.7235 million tons of wastewater in 2008. The average concentration COD was cut off from 80mg/L in 2007 to 46.2mg/L, and a total of 582.5 tons of COD was reduced. 5.405 million tons of water was reused, and 249.7 tons of COD was reduced through water reclamation. The total reduction of COD was 832.2 tons in 2008. Nine Dragons won the provincial award due to a high ratio of water reclamation in 2008.

In 2009, Nine Dragons conducted a project of recollection and reuse of residual heat from the papermaking line. The company, together with Finland TM, developed and utilized a heat recovery system to save the energy resulting from excessive high temperature of steam discharged in the process of paper drying. This system cost 23.06 million CNY for equipment installation. In a packaging product line with a capacity of around 1million tons per year, 180,259 tons of steam is used for heating ultra-clean water for pulp making and clean water for paper making. By the introduction of this system, the production line can save 22,172 tce of energy per year, equaling to 17.74 million CNY in assuming coal price being 800 CNY/t.

The other technological upgrading of Nine Dragons included cooling tower construction to recycle the cooling water. The water used in high quality paper-making process is returned for producing the low quality paper. The wastes are burnt for heat by circulating fluidized bed technology if they can not be recycled. The residual of the burned wastes are used to make chopping block of forklift. Thus solid wastes of the company almost reach zero emission.

As shown in Table 14, the contents of energy audit in Nine Dragons are similar with that of Zhenhui and focus on the identification of energy management status, energy saving potential and technological modifications. According to the analysis of energy saving potentials, Nine Dragons should draw attention to basic institutions and management of equipment operations. Six proposals of energy saving and technological modification were put forward, including reconstruction of pump in boiler house, reconstruction of pulp pump, reusing the heat of exhaust vapors, etc. The total investment of the six proposals is estimated to be 16.4 million CNY. These projects may save 37,176 tce of energy, reduce 29.978 tons of CO_2 and 738.28 tons of SO_2.

During 2004 to 2007, almost all environmental indicators, including the amount of coal use, fresh water consumption, COD and ammonia nitrogen emissions, had a decrease trend, especially in 2007. The reason is that the production capacity was expanding continuously during 2004 to 2006. However, several technological reconstruction projects described above were put into practice in 2007 and received obvious achievements. The details are expressed in Table 15. As the result, Nine Dragons got several awards on energy saving and 10 million CNY financial subsidies as well.

Regarding the external GSCM practices, Nine Dragons interacts with its downstream customers, mainly the packing enterprises. They supervise each other on environmental management. Nine Dragons categorizes its clients based on certain indicators including environmental factors. The Department of Environmental Protection and Resource Recycling sets up waste paper recovery unit to collect waste paper from downstream customers as raw materials for production. Most waste paper as raw materials for Nine Dragons originates from the U.S., EU and Japan, where generally have strict inspection procedures for the export of recyclables. When waste paper enters into China, it is inspected by custom and the commercial agency as well. The containers must be disinfected 24 hours before being opened for test. Nine Dragons holds supplier conference once a year, mainly to exchange information on material supply, environmental management and so on. Therefore, we can infer that Nine Dragons has started the second stage of GSCM practices, such as ‘environmentally preferable purchasing’, ‘evaluation and selection of upstream suppliers'. Some activities concerning the third stage have been practiced like 'environmentally conscious design and manufacturing', 'eco-design in cooperation with suppliers'. For example, Nine Dragons required suppliers to provide environment-friendly products, set standard for suppliers' environmental behaviors and evaluate them, conduct researches for developing environment-friendly products such as the 80g/m^2 light cardboard with suppliers, reduced packing waste in cooperation with suppliers, etc.

Table 14: The contents of energy audit of Nine Dragons

Energy management institutions	Current status	Energy management framework has been set up from the top to departments. There are employees working on energy management.
	Problems	Weak in systematic arrangement. Energy managers haven't attended to provincial trainings and did not achieve certifications. There is no specific staff responsible for energy management at workshop level.
	Suggestions	To specify responsible persons at workshop and process level based on current framework. Department of energy management should equip portable energy monitoring instruments to identify further energy saving potentials. Extensive training shall be carried out to promote awareness of the staffs.
Energy management system	Current status	Water, electricity, steam, coal, gas and raw materials are in the range of energy and resource management.
	Problems	Lack of systematic energy management system, including energy procurement and assessment, energy financial management, energy production management, energy measuring instruments, energy use evaluation and rewards, and energy managers and operators' training system.
	Suggestions	To reinforce the trainings and information sharing on energy saving
Energy measurement management	Current status	Measurement systems cover coal, electricity, heating power, water and steam
	Problems	No measuring system of cooling water and compressed air; No measurement of main energy consuming equipments; The ratio of measuring instruments is 42.15%, with the ratio in good condition being 94.27%; difficult to subdivide the quota for quantitative assessment.
	Suggestions	To improve the rate of measuring equipments for main electric equipments and processes; enhance the patrol and verification of the meters.
Energy statistics management	Current status	Primary statistics was established; data and records are processed electronically.
	Problems	Data recording and analysis are incomplete; no record for related parameters and basic management needs to be strengthened; No systematic statistic analysis; in particular, the material flow analysis is not developed.
	Suggestions	To establish detailed and classified formats for energy use statistics of each process; to find out the reason of excessive energy use for improvement by comparing the energy consumption index.
Energy quota management	Current status	Quota management is practiced in some departments but not reach team level.
	Problems	No statistical data at the process level due to the product varieties and measuring problems; The main index of energy use is rough and can't reflect the actual performance of working procedures, major energy consuming and energy transformation devices.
	Suggestions	To establish quota management for all processes, develop statistical analysis of energy use and establish the indicator for assessment; to establish material flow analysis system, reward and penalty system, introduce the energy evaluation into the company management system.

Table 15: Environmental performance changes of Nine Dragons

Year		2007	2006	2005	2004
Total sales (in billion CNY)		1.665	2.649	1.706	0.98
Air pollution index	Coal use (10,000 t)	31.82	109.48	46.94	23.3
	Exhaust gas (billion m^3)	2.546	9.853	4.225	2.09
	SO_2 (t)	51.6	1916.0	267.5	183.2
	NO_x (t)	549	5474	--	--
	Soot (t)	11.3	396	353	17.5
Water pollution index	Industrial water use (million t)	11.96	58.70	--	--
	Fresh water use (million t)	6.10	16.00	8.20	3.90
	Wastewater treatment amount (million t)	2.83	16.00	--	--
	Wastewater amount below emission standard (million t)	2.83	16.00	8.20	3.90
	COD (t)	11.4	1600	82	38.5
	NH_4-N (t)	--	7.6	7.6	3.6
Industrial solid waste (million t)		0.1438	0.2235	0.2033	0.0751

3.3.3.2 Further GSCM opportunities of Nine Dragons

At current phase, GSCM practices of Nine Dragons focuses on internally environmental management activities. According to the energy audit report of Nine Dragons, there exists a lot of problems on energy management. Besides reinforcing technological upgrading and pollution control of wastewater, exhaust gas and solid wastes, carrying out the suggestions proposed during the energy audit is an important task in near future. Moreover, Cleaner production audit needs to be considered. As Nine Dragons has put the second even the third stage of GSCM activities into practice. Promoting these activities continuously is critical for improving its environmental management.

4. Brief summary

We explore the overall status and determinant factors of GSCM activities adopted by the firms located in the Yangtze River delta. The surveyed companies perform relatively better on GSCM practices if comparing with the samples of a previous survey in China (Zhu et al., 2008). Nevertheless, the overall level of GSCM does not change fundamentally. A firm's environmental efforts in cooperation with external members of the supply chain are quite marginal. Among a larger range of determinant factors of GSCM activities classified in this study, external pressures from regulatory, domestic clients and competitors are significantly and positively associated with L_{GSCM}. A firm's learning capacity determines L_{GSCM} as an internal factor. This result provides essential implications for Chinese policy makers. More interactions should be created to facilitate the concerns of external stakeholders which may translate into pressures for a firm's efforts in GSCM practices. It is also necessary to enhance firms' understanding of the advantages of GSCM as an innovative strategy of CEM.

This research also conducted case studies on GSCM practices of three target companies, namely

SDS, Zhenhui and Nine Dragons. It is confirmed that the GSCM practice level of multinational, joint venture and foreign-funded companies is higher than domestic ones. This implies a close relationship between company size, ownership and the level of GSCM, which is consistent with the finding from our questionnaire survey. Although obvious improvements of economic and environmental performances are observed in the three cases, their environmental efforts basically focused on energy saving and emission reduction, and failed to substantially penetrate into the advanced stage of GSCM practices. This research showed us the possible way forward for promoting GSCM practices in China. The currently mandatory environmental policies are effective at certain degree in enhancing firm's environmental management, like the cases of Zhenhui and Nine Dragons. However, compared with government policy-driven case, market actor-driven model is more sustainable for GSCM activities as it is based on mutual support and communication among the core companies, suppliers and customers, and can extend the green ideology through the supply chain rapidly. Besides regulative enforcement, the government shall provide more support which are usually neglected. Large state-owned companies, as the leading policy practitioner, should play more active role in GSCM diffusion.

References:

Carter, C.R., Ellram, L.M., Kathryn, L.M., 1998. Environmental purchasing: benchmarking our German counterparts. International Journal of Purchasing and Materials Management, 34(4), 28-38.

Delmas, M., 2002. The diffusion of environmental management standards in Europe and the United States: an institutional perspective. Policy Science, 35, 91-119.

Fiksel, J., 1996. Design for the environment: Creating eco-efficiency products and processes. McGraw-Hill: New York, USA.

Hall, J., 2000. Environmental supply chain dynamics. Journal of Cleaner Production, 8, 455-471.

Handfield, R.B., 1996. Green supply chain: best practices from the furniture industry proceedings. Annual meeting of the Decision Sciences Institute, U.S., 1295-1297.

Hart, S., 1995. A natural resource-based view of the firm. Academy of Management Review, 20(4), 30-37.

Hervani, A.A., Helms, M.M., Sarkis, J., 2005. Performance measurement for green supply chain management. Benchmarking: An International Journal, 12(4), 330-353.

Madu, C.N., Kuei, C., Madu, I.E., 2002. A hierarchic metric approach for integration of green issues in manufacturing: a paper recycling application. Journal of Environmental Management, 64, 261-272.

Prahinski, C., Kocabasoglu, C., 2006. Empirical research opportunities in reverse supply chain. Omega, 34(6), 519-532.

Sarkis, J., 1998. Theory and methodology evaluating environmentally conscious business practices.

European Journal of Operational Research, 107, 159-174.

SEPA (State Environmental Protection Administration), 2003. Announcement on environmental protection auditing to the companies applying to be listed or for refinancing (In Chinese). Available from: http://www.sepa.gov.cn/; [accessed 28.05.08].

Snir, E.M., 2001. Liability as a catalyst for product stewardship. Production and Operations Management, 10(2), 190-206.

Zhu, Q.H., Sarkis, J., 2006. An inter-sectoral comparison of green supply chain management in China: Drivers and practices. Journal of Cleaner Production, 14, 472-486.

Zhu, Q.H., Sarkis, J., Cordeiro, J.J., Lai, K.H., 2008. Firm-level correlates of emergent green supply chain management practices in the Chinese context. Omega, 36(4), 577-591.

Zsidisin G.A., Siferd, S.P., 2001. Environmental purchasing: A framework for theory development. European Journal of Purchasing and Supply Management, 7(1), 61-73.

The Study of Taiwan Resources Recycle Fee and Subsidy Mechanisms of Waste Plastic Container

Wei-Lung Huang[1]

Abstract

This study would survey the mechanism, effects and problem of waste plastic container recycling system in Taiwan, and found that the key success factors of this recycling system are the resources recycle fee (RRF) and subsidy mechanisms. Then this paper employs the mathematical model to analyze the optimal RRF and Subsidy, and this model try to include the assumptions about the externality of waste plastic container, environmental consciousness of individuals and the balance of budge. Results of this study suggest that under current conditions, RRF and subsidy should not be optimal. Thus, this study advice the relationship between RRF and Subsidy should be revenue decoupling.

1 Correspondence: Wei-Lung Huang, Department of Finance, China University of Science and Technology, Taiwan. Tel: (02)27864501; Fax: (02) 27864501; Email: hippoobee@yahoo.com.tw. Assistant Professor and Chairman, Finance, China University of Science and Technology .

1. Introduction

Waste container has been classified as "Due Recyclable Waste (DRW)" by Environmental Protection Administration (EPA) in Taiwan and its resource recycling activities has been effectively regulated by the Recycling Fund Management Board (RFMB) which is established by EPA in 1998. Based on Waste Disposal Act, EPA has classified 6 groups (13 categories) DRW containers, which are iron container, aluminum container, glass container, paper container(aseptic cartons, paper cartons, paper tableware), plastic container(PET, PVC, PE, PP, PS form, PS non-form) and pesticide container.

For the increment of recycling efficiency and the reduction of implementation cost, RFMB set the Four-in-One Resource Recycling Program (Four-in-One Program) to implement the recycling system of DRW containers. The purpose of Four-in-One Program is to combine its four players (community residents, municipal garbage collection teams, recycling enterprise and RFMB) to promote the recycling activities, establish effective recycling scheme and provide convenient recycling channels of DRW containers.

The clean-up, treatment and recycling fee (resources recycle fee, RRF) and subsidy are the key factors of Four-in-One Program, and for the balance of budge, RFMB set the relationship between RRF and subsidy is linear. For there are the external cost of DRW containers and the external benefit of their recycling material, many countries use the economic incentives (RRF and subsidy) to internalize the above externality.

There are some kinds external cost about the linear relationship between RRF and subsidy in empirically, like the lobbing cost of the interest groups, so the first purpose of this paper is to discuss the present situation (2010) of Four-in-One Program and the problem of the linear relationship between RRF and subsidy. Its reason is when the targets or quantity of subsidy increase, then the quantity of RRF should also raise. And for the higher and higher environmental consciousness, many countries claim more and more categories DRW containers and the recycling amount of DRW containers (proportional to the amount of subsidy) has increase dramatically. Thus, more and more Designated Responsible Entities (DREs) who submitted RRF question the targets and amount of subsidy in Taiwan.

The purposes of RRF and subsidy should be hardly achieved for they are not consistent with the linear relationship between RRF and subsidy, so the second purpose of this paper is to introduce the function of the linear relationship between RRF and subsidy, and then argue for a government's welfare-maximization RRF and subsidy problem. The purpose of RRF is to internalize the external cost of DRW containers then reduce their amount which DREs use. The purpose of subsidy is to internalize the external benefits of recyclable resources then promote the resource recycling scheme which turns DRW containers to recyclable resources. For the external cost of DRW containers should not be proportional to the external benefit of recyclable resources, the linear relationship between RRF and subsidy might not be suitable to their purposes.

The purpose of this paper is to understand the impact of the linear relationship between RRF and subsidy on the model of government's welfare-maximization RRF and subsidy. Then the paper is organized as follows. Section 1 is introduction. Section 2 is the present situation and the problem of Four-in-One Program. Section 3 develops the model of government's welfare-maximization RRF and subsidy and performs numerical simulations. The last section concludes.

2. The present situation and the problem of Four-in-One Program

For regulating the resource recycling activities in Taiwan, EPA the RFMB was established by EPA in 1998. RFMB would handle the receipt and reimbursement of RRFs, the administration of the recycling industry, the verification scheme of resource recycling activities, and the subsidy of recycling enterprise, local governments and the groups which promoted resource recycling activities. The RFMB consists of a Fee Review Committee, Auditing and Certification Supervisory Committee and Technical Advisory Committee (See **Figure 1**).

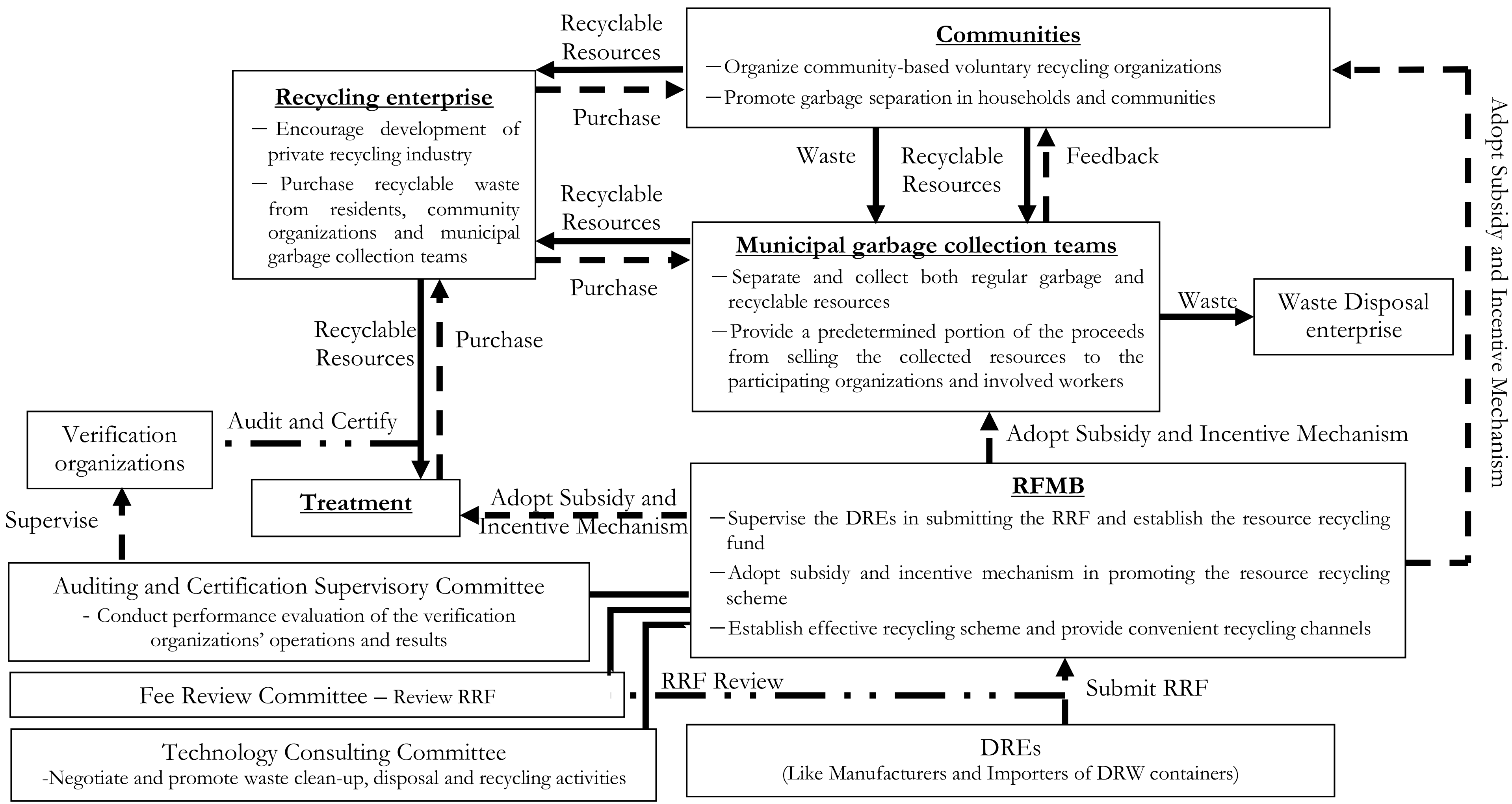
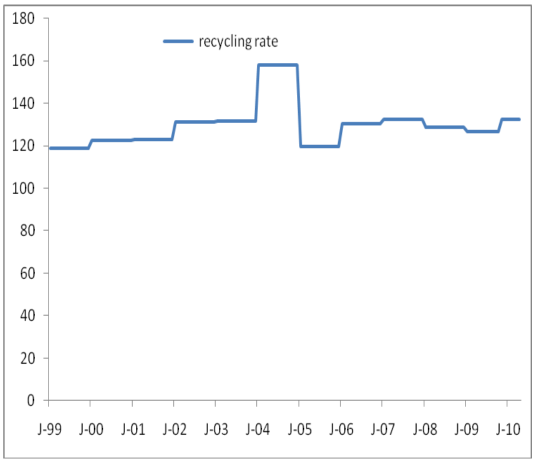
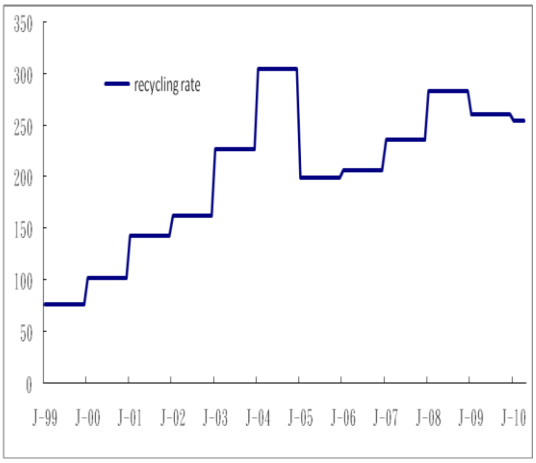


Figure 1 The implementation system established by the Four-in-One Resource Recycling Program

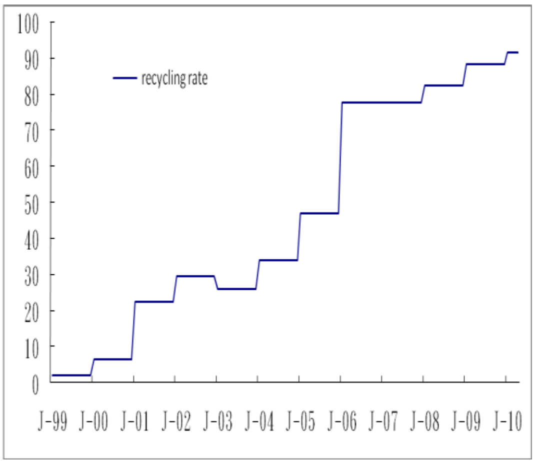
Data Source: This paper modified the homepage of RFMB.



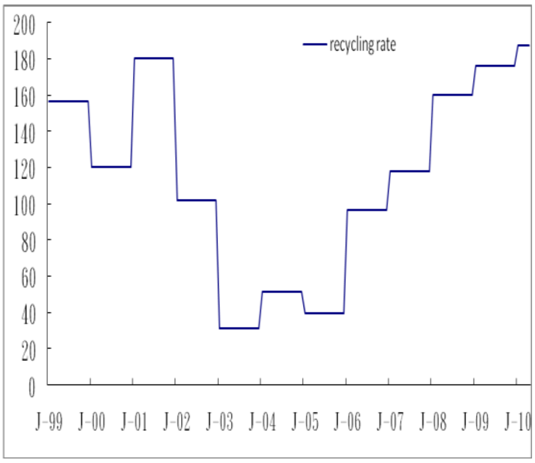
(a)The recycling rate of PET
(1999/1~2010/4)



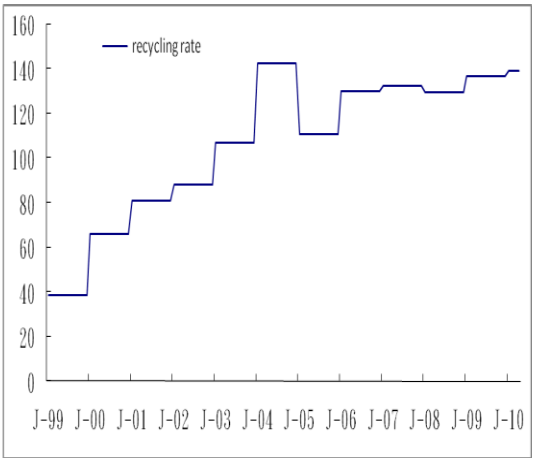
(b) The recycling rate of PVC
(1999/1~2010/4)



(c)The recycling rate of PS non-form
(1999/1~2010/4)



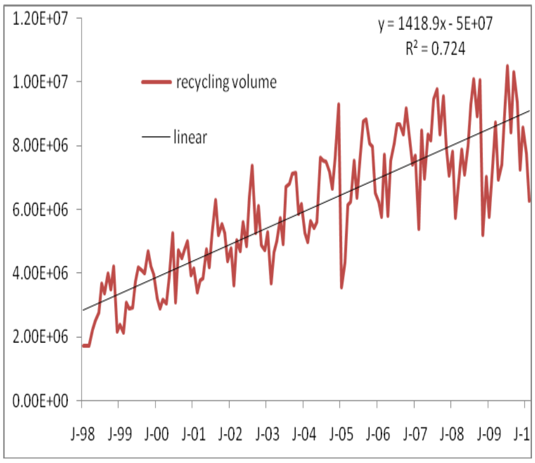
(d)The recycling rate of PS form
(1999/1~2010/4)



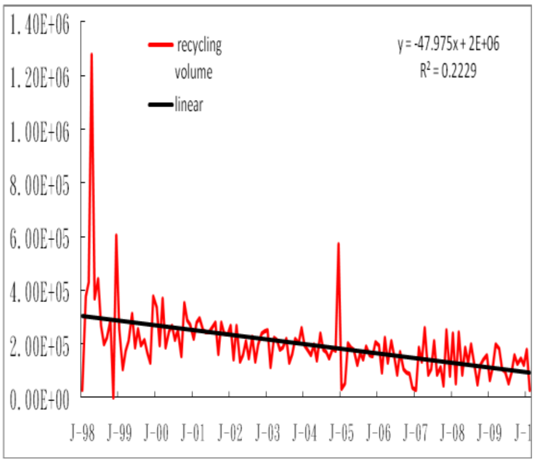
(e) The recycling rate of PP/PE
(1999/1~2010/4)

Figure 2 The recycling rate of 5 categories DRW plastic containers

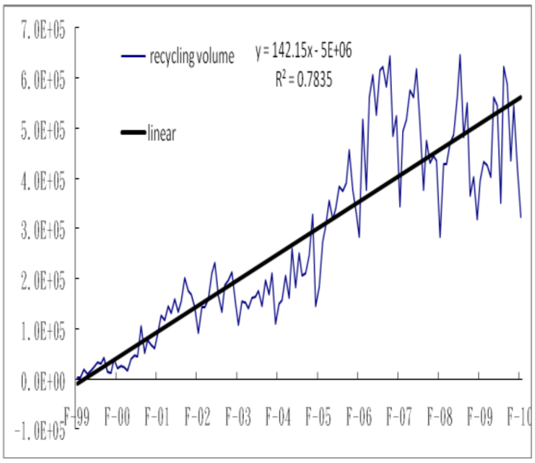
Data Source: This paper modified the data of RFMB.



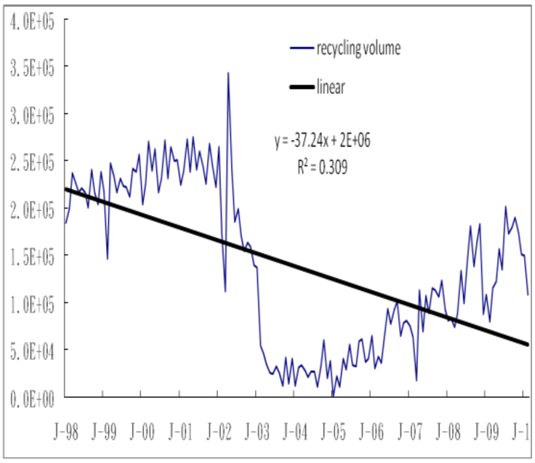
(a) The recycling volume of PET (1998/1~2010/2)



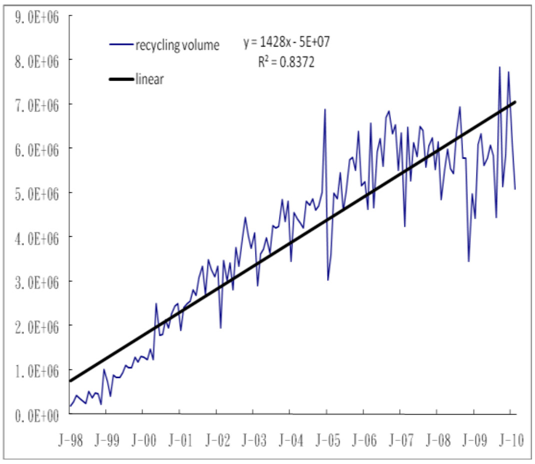
(b) The recycling volume of PVC (1998/1~2010/2)



(c)The recycling volume of PS non-form (1999/2~2010/2)



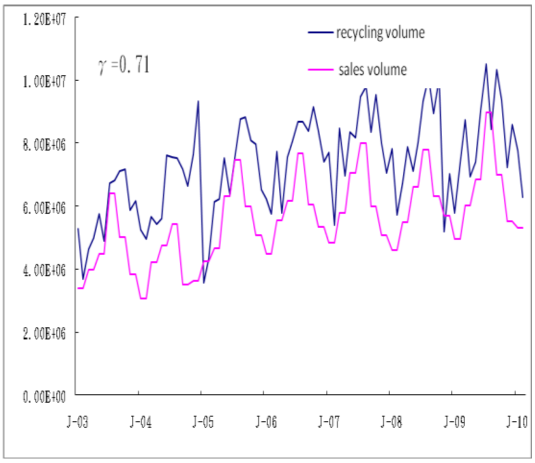
(d)The recycling volume of PS form (1998/1~2010/2)



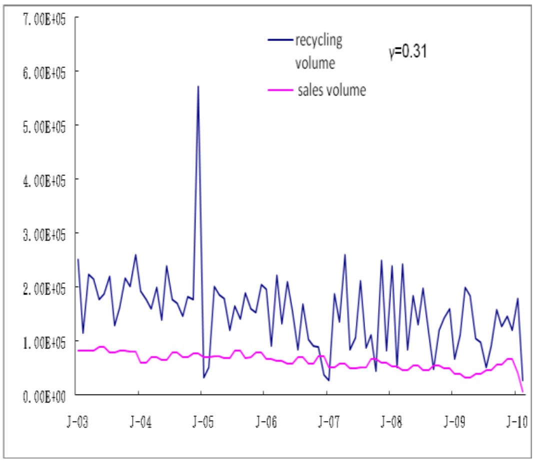
(d)The recycling volume of PP/PE (1998/1~2010/2)

Figure 3 The recycling volume and trend line of 5 categories DRW plastic containers

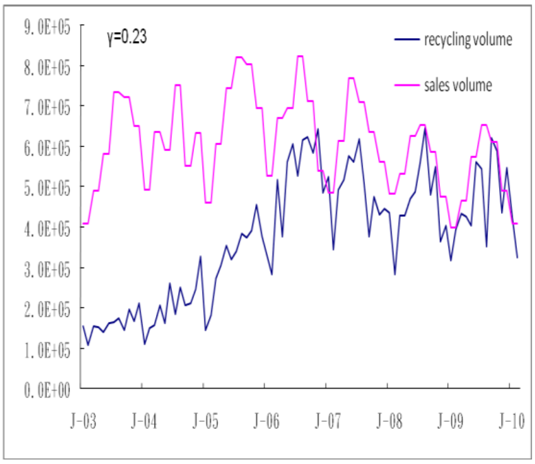
Data Source: This paper modified the data of RFMB.



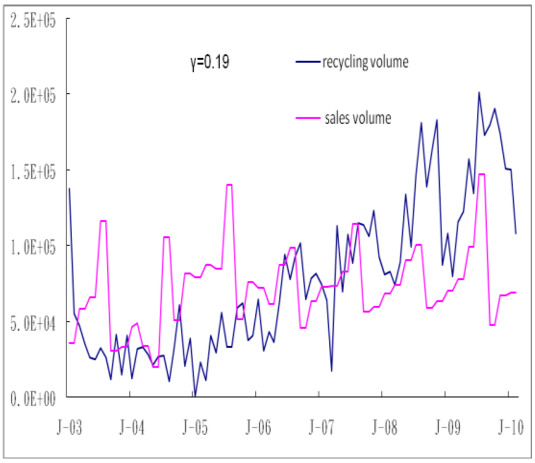
(a)The recycling volume and sales volume of PET(2003/1~2010/2)



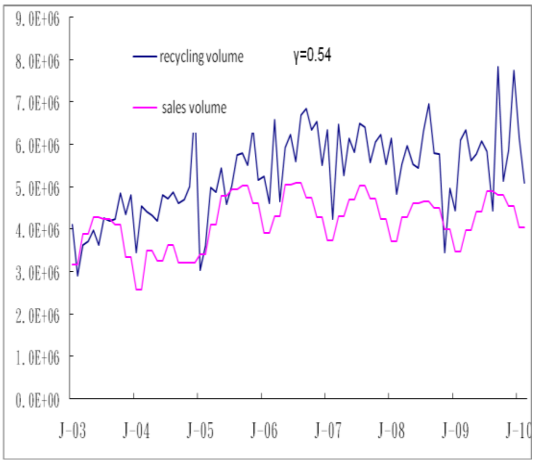
(b) The recycling volume and sales volume of PVC (2003/1~2010/2)



(c)The recycling volume and sales volume of PS non-form(2003/1~2010/2)



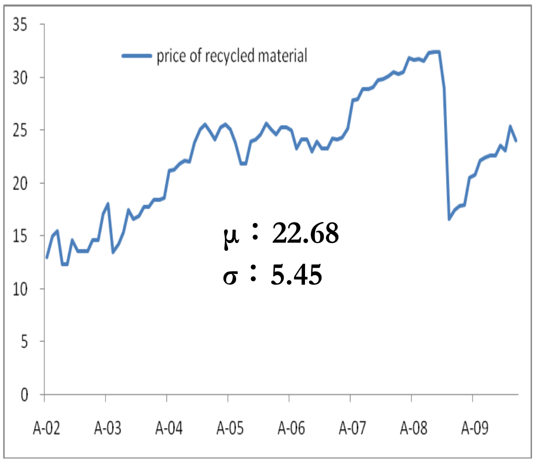
(d) The recycling volume and sales volume of PS form (2003/1~2010/2)



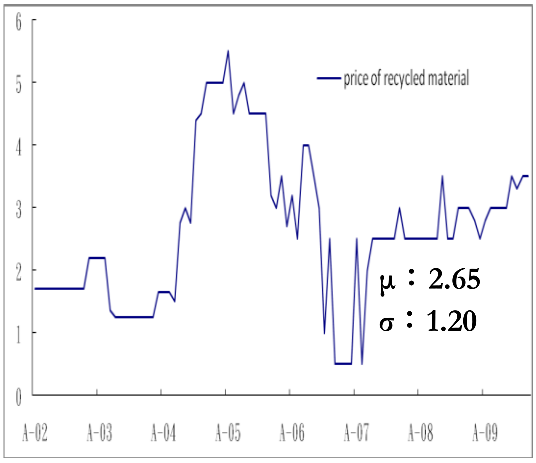
(e)The recycling volume and sales volume of PP/PE (2003/1~2010/2)

Figure 4 The recycling volume, sales volume and correlation coefficiency of 5 categories DRW plastic containers

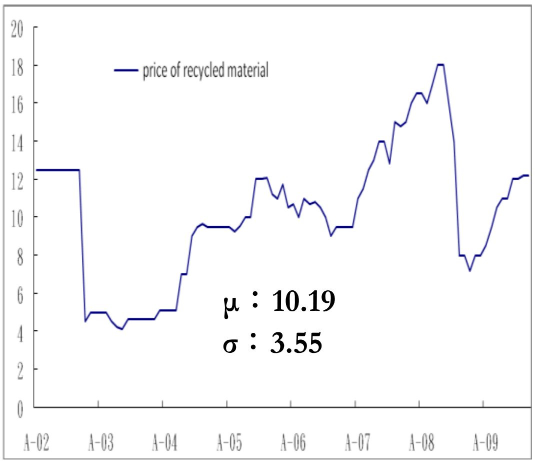
Data Source: This paper modified the data of RFMB.



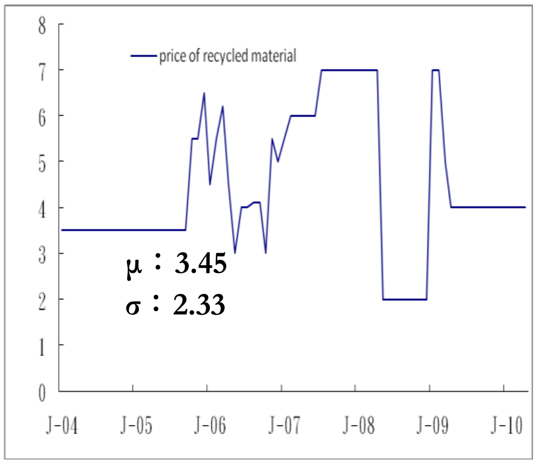
(a) The price of recycled material on PET (2002/4~2009/12)



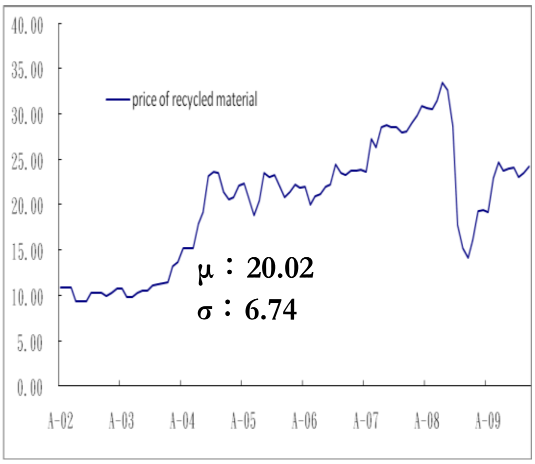
(b) The price of recycled material on PVC (2002/4~2009/12)



(c)The price of recycled material on PS non-form (2002/4~2009/12)



(d) The price of recycled material on PS form (2004/1~2010/4)



(e) The price of recycled material on PP/PE (2002/4~2009/12)

Figure 5 The mean and standard deviation of the price of 5 categories DRW plastic containers' recycled material

Data Source: This paper modified the data of RFMB.

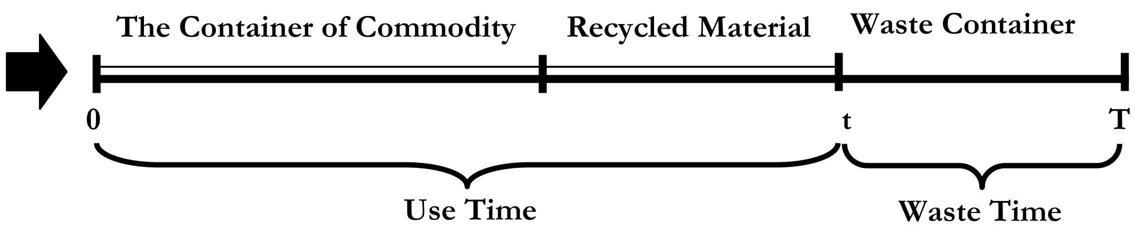
3. The model

3.1 The model with no externality of DRW containers

3.1.1 The model of the maximization of the net individual utility of a DRW container

This model assumes that every individual knows its environmental consciousness of DRW containers (c), and for $\forall i, c_i$ is constant and $c_i \neq c_j$ when $i \neq j$. The idea of the length and use time on a DRW container' life cycle could see figure 7. The length of a DRW containers' life cycle is T (as [0,T] in figure 7(a)), and it could be divided with three stages: the container of commodity ([0,A)), waste container ([A,B)) and recycled material([B,T]). The use time of a DRW container by every individual is t (as [0,t) in figure 7(b)) which combine with two stages: the container of commodity and recycled material, and the rest is waste time.

(a) The life cycle of a DRW container



(b) The use time of a DRW container' life cycle

Figure 7 The length and use time of a DRW container' life cycle

Data Source: This paper.

The monetary utility which every individual get from a DRW container by unit time is u which is proportional to the environmental consciousness of every individual, so 0< u = g(c). The individual utility which every individual gets from a DRW container is U, which should be proportional to the magnitude which u multiple with **t**, so 0 < $U = G(c,t) = \int_0^t u\,dx$ and $\partial G/\partial c > 0$, $\partial G/\partial t > 0$, $\partial^2 G/(\partial c \partial t) = \partial^2 G/(\partial t \partial c) > 0$, $\partial^2 G/(\partial c)^2 < 0$, $\partial^2 G/(\partial t)^2 < 0$.[2]

RRF (F) is proportional to the use time of a DRW container and there is the linear relationship between RRF and subsidy (S), so 0 < F=H(t), S=K*H(t) and

---

[2] For empirically, the use time of a DRW container by individual should be proportional to the environmental consciousness of every individual, so this model assumes $\partial^2 G/(\partial u_i \partial t) = \partial^2 G/(\partial t \partial u_i) > 0$.

$K>0$, $\partial H/\partial t>0$, $\partial^2 H/(\partial t)^2<0$. Every individual gets the monetary utility and pays RRF on the use time of a DRW container, and gets subsidy on its waste time. There is no difference on time preference.

The net individual utility of a DRW container by every individual is IU which is the function of subsidy, RRF, individual's monetary utility and the use time of a DRW container, so

$$IU=W(c,t)=\int_0^t (u-F)dx+\int_t^T Sdx=G(c,t)-\int_0^t H(x)dx+\int_t^T KH(x)dx$$

The decision problem of a DRW container by individual i is to choose t to maximize its net individual utility. This problem amounts to

$$\operatorname*{Max}_t W(c,t)=G(c,t)-\int_0^t H(x)dx+\int_t^T KH(x)dx \qquad (1).$$

The first order condition of (1) is

$$\partial IU/\partial t=\partial G(c,t^*)/\partial t-(K+1)H(t^*)=0$$

$$\Rightarrow \partial G(c,t^*)/\partial t=(K+1)H(t^*) \qquad (2).$$

The meaning of (1) is the marginal utility is equal to the sum of marginal subsidy and marginal RRF (=(K+1)* marginal RRF)on the optimal use time.

The second order condition of (1) is

$$\partial^2 IU/(\partial t)^2=\partial^2 G(c,t^*)/(\partial t)^2-(K+1)[\partial H(t^*)/\partial t]<0 \qquad (3).$$

The meaning of (2) is the increasing rate of marginal utility is less than the sum of increasing rate of marginal subsidy and marginal RRF (=(K+1)* marginal RRF)on the optimal use time.

Lemma 1: The more is the environmental consciousness of DRW containers by every individual, the more is its use time.

Proof: The total derivative of (2) is

$$[\partial^2 G(c,t^*)/(\partial t)^2]dt+[\partial^2 G(c,t^*)/(\partial t\partial c)]dc\Big|_{t=t^*}=(K+1)[\partial H(t^*)/\partial t]dt.$$

For $\partial^2 G/(\partial t\partial c)>0$ and (2), so

$$dt/dc\Big|_{t=t^*} = -\partial^2 G/(\partial t \partial c)/\{\partial^2 G(c,t^*)/(\partial t)^2 - (K+1)[\partial H(t^*)/\partial t]\} > 0 . \quad \text{Q.E.D.}$$

Lemma 2: The more is the environmental consciousness of DRW containers by every individual, the more is its net individual utility.

Proof: The derivative of (1) by c is

$$\underset{t}{Max}\, W(c,t) = G(c,t) - \int_0^t H(x)dx + \int_t^T KH(x)dx$$

$$\partial W/\partial c = \partial G/\partial c + (\partial G/\partial t)(dt/dc) - (K+1)(\partial H/\partial t)(dt/dc)$$

For $\partial G/\partial c > 0$ and (1), so $\partial W/\partial c\big|_{t=t^*} = \partial G/\partial c\big|_{t=t^*} > 0$. Q.E.D.

3.1.2 The model of the maximization of the net social utility of DRW containers

This model would include the assumption and conclusion of 3.1.1. From **Lemma 1**, the use time of a DRW container by every individual is proportional to the environmental consciousness of every individual, so t = f(c), $\partial f/\partial c > 0$.

The government could set the dynamic adjustment relationship between every individual's environmental consciousness of DRW containers and its use time by Four-in-One Program which adopts incentive mechanism in promoting the resource recycling scheme and provides convenient recycling channels. Thus, the dynamic adjustment function of the use time of a DRW container is

$$t' = df(c)/dc = \eta \text{ ，} \eta > 0 \qquad (4).$$

For the derivative of (2) by c and (4), the dynamic adjustment function of RRF is

$$F' = dH(t)/dc = \{\eta[\partial^2 G/(\partial t)^2] + \partial^2 G/(\partial t \partial c)\}/(K+1) \qquad (5).$$

For the linear relationship between RRF and subsidy, the dynamic adjustment function of subsidy is

$$S' = K\{\eta[\partial^2 G/(\partial t)^2] + \partial^2 G/(\partial t \partial c)\}/(K+1) \qquad (6).$$

The subsidy amount of every individual (IS(t)) which is given by the government is $IS(t) = \int_{t(c)}^{T} KH(x)dx - \int_0^{t(c)} H(x)dx$, so the dynamic adjustment function of the subsidy amount of every individual is

$$IS' = dIS/dc = -\eta(K+1)H(t) \quad (7).$$

The government doesn't know every individual's environmental consciousness of DRW containers, but knows their probability density function that is $\{c \mid \int_{\underline{c}}^{\bar{c}} v(\tau)d\tau = 1, \quad c \in [\underline{c}, \bar{c}]\}$, $\underline{c}$, $\bar{c}$ are the lower and upper bound of their environmental consciousness and positive. There are N individuals, total subsidy amount (TS(t)) should be less than or equal to the budget of government(G is constant), so the budget constraint of government is

$$TS(t) = N\int_{\underline{c}}^{\bar{c}} IS(t)v(\tau)d\tau \leq G \quad (8).$$

The budget of government which includes external cost would be θG, $\theta > 1$.

From (1) and the above assumptions, so the net social utility of a DRW container is SU, and government would choose policy variable (η) to optimize the net social utility of a DRW container under the budget constraint and the above dynamic adjustment functions which are based on every individual's optimal use time of DRW containers (the result of 3.1.1). This is because government could control the dynamic adjustment function of the use time of a DRW container, RRF, subsidy and the subsidy amount of every individual. Thus, this model is

$$\underset{\eta}{Max} \ SU(c) = N\int_{\underline{c}}^{\bar{c}} [G(c,t) + IS(t)]v(\tau)d\tau - \theta G \quad (9),$$

Subject to (4), (5), (6), (7), (8), $t(\underline{c})$ and $t(\bar{c})$ are not constant.

The Hamiltonian function (HF(t)) is

$$HF(t) = N[G(c,t) + IS(t)]v(c) + \alpha\eta + [(\beta+\gamma K)/(K+1)]\{\eta[\partial^2 G/(\partial t)^2] + \partial^2 G/(\partial t \partial c)\}$$

$$-\delta\eta(K+1)H(t) - \lambda NIS(t)v(c)$$

when α, β, γ, δ and λ are the multipliers of (4), (5), (6), (7) and (8).

Its necessary conditions are

$$\partial HF/\partial\eta = \alpha + [(\beta + K\gamma)/(K+1)]\partial^2 G/(\partial t)^2 - \delta(K+1)H(t(c)) = 0 \quad (10),$$

$$\alpha' = -\partial HF/\partial t = -\{N[\partial G/\partial t - (1-\lambda)(K+1)H(t)]v(c) - \delta\eta\,\partial^2 G/(\partial t)^2$$

$$+[(\beta+\gamma K)/(K+1)][\eta(\partial^3 G/(\partial t)^3)+\partial^3 G/(\partial t\partial c\partial t)]\} \qquad (11),^3$$

$$\beta'=\gamma'=\delta\eta \qquad (12),$$

$$\delta'=-N[(1-\lambda)v(c)] \qquad (13).^4$$

From (13), if the subsidy amount of the individuals which environmental consciousness is c is raised one dollar by government, its net social utility of a DRW container would increase $N[(1-\lambda)v(c)]$ dollar.

Proposition 1: $\delta(t)=-N(1-\lambda)V(c)$ when $V(c)=\int_{\underline{c}}^{c} v(\tau)d\tau$.

Proof: The integration of (13) by c is

$$N(1-\lambda)\int_{\underline{c}}^{c} v(\tau)d\tau = N(1-\lambda)V(c)=-\delta(t). \qquad \text{Q.E.D.}$$

Lemma 3: The subsidy amount of the individual which use time is less than or equal to t(c) is raised one dollar by government, its net social utility of a DRW container would increase $N[(1-\lambda)V(c)]$ dollar.

Proof: For (4), the individuals which use time is less than or equal to t(c) should be the same with the individuals which environmental consciousness is less than or equal to c. And for **Proposition 1**, if the subsidy amount of the individuals which environmental consciousness is less than or equal to c is raised one dollar by government, its net individual utility of a DRW container would increase $NV(c)$ dollar, but its budget of government increases $N\lambda V(c)$, so its net social utility of a DRW container would increase $N[(1-\lambda)V(c)]$ dollar. Q.E.D.

Proposition 2: $F(t(c))=(1-\lambda)V(c)(2\eta+1)[\partial^2 G/(\partial t)^2]/[(K+1)v(c)]$.

Proposition 3: $S(t(c))=K(1-\lambda)V(c)(2\eta+1)[\partial^2 G/(\partial t)^2]/[(K+1)v(c)]$.

Proof: The derivative of (10) by t is

$$\alpha'=-\{[(\beta'+K\gamma')/(K+1)+\delta][\partial^2 G/(\partial t)^2]+[(\beta+K\gamma)/(K+1)][\eta\partial^3 G/(\partial t)^3$$

---

3 For the derivative of (2) by t, $dH(t)/dt=[\partial^2 G/(\partial t)^2]/(K+1)$.

4 The Kuhn-Tucker Condition is $\lambda[G-N\int_{\underline{c}}^{\bar{c}} IS(t)v(\tau)d\tau]=0$ when $\lambda\geq 0$. The Transversality Condition is $\alpha(\bar{c})=\alpha(\underline{c})=\beta(\bar{c})=\beta(\underline{c})=\gamma(\bar{c})=\gamma(\underline{c})=\delta(\bar{c})=\delta(\underline{c})=0$.

$$+\partial^3 G/(\partial t\partial c\partial t)]+\delta'(K+1)H(t)\} \quad (15).$$

For (12) and (13), (15) would be

$$\alpha' = -\delta(\eta+1)[\partial^2 G/(\partial t)^2]-[(\beta+K\gamma)/(K+1)][\eta\partial^3 G/(\partial t)^3+\partial^3 G/(\partial t\partial c\partial t)]$$

$$+N[(1-\lambda)v(c)](K+1)H(t) \quad (16).$$

And for (2) and (14), the function that subtract (11) from (16) is

$$-N(1-\lambda)V(c)(2\eta+1)[\partial^2 G/(\partial t)^2]+N(K+1)H(t)v(c)=0$$

$$\Rightarrow F(t(c))=H(t(c))=(1-\lambda)V(c)(2\eta+1)[\partial^2 G/(\partial t)^2]/(K+1)v(c)$$

$$\Rightarrow S(t(c))=KH(t(c))=K(1-\lambda)V(c)(2\eta+1)[\partial^2 G/(\partial t)^2]/(K+1)v(c) \qquad \text{Q.E.D.}$$

Lemma 4: The determinant whether government would set the RRF and subsidy or not is the multiplier of budget constraint of government (λ), this is because $\text{sign}[F(t(c))]=\text{sign}[S(t(c))]=\text{sign}(\lambda-1)$.

Proof: For **Proposition 2**, **Proposition 3**, $V(c)>0$, $(K+1)>0$, $\eta>0$, $v(c)>0$ and $\partial^2 G/(\partial t)^2<0$, so $\text{sign}[F(t(c))]=\text{sign}[S(t(c))]=\text{sign}(\lambda-1)$. Q.E.D.

Lemma 5: The RRF and subsidy of the individual with the least environmental consciousness($\underline{c}$) tend to zero.

Proof: For $V(\underline{c})=\int_{\underline{c}}^{\underline{c}} v(\tau)d\tau \to 0$ ，so $F(t(\underline{c}))\to 0$ and $S(t(\underline{c}))\to 0$. Q.E.D.

3.1.3 The budget of government by two stages

This model would include the assumption and conclusion of 3.1.1 and 3.1.2, and assumes that the government would divide the budget of government by two stages, one is the basic waste time ($=T-t(\bar{c})$), the other is the rest waste time($=t(c)-t(\bar{c})$), so (11) becomes

$$N\int_{\underline{c}}^{\bar{c}}\{[\int_{t(\bar{c})}^{T}F(x)dx-\int_{0}^{t(\bar{c})}S(x)dx]+[\int_{t(c)}^{t(\bar{c})}F(x)dx+\int_{t(c)}^{t(\bar{c})}S(x)dx]\}v(\tau)d\tau \le G.$$

And the budget of the basic waste time which is constant is G_B, so

$$N\{\int_{\underline{c}}^{\bar{c}}[\int_{t(c)}^{t(\bar{c})}F(x)dx]v(\tau)d\tau+\int_{\underline{c}}^{\bar{c}}[\int_{t(c)}^{t(\bar{c})}S(x)dx]v(\tau)d\tau\}\le G-G_B \qquad (17).$$

For **Lemma 1** and Fubini's theorem, (17) becomes

$$N\int_{\underline{c}}^{\bar{c}}[F(t(\tau))+S(t(\tau))][1-V(\tau)]d\tau\le G-G_B \qquad (18).$$

For **Proposition 2** and **Proposition 3**, (18) becomes

$$N(1-\lambda)(2\eta+1)\int_{\underline{c}}^{\bar{c}}V(\tau)(1-V(\tau))[\partial^2G/(\partial t)^2]/v(\tau)\,d\tau\le G-G_B \qquad (19)$$

And for N>0, $2\eta+1>0$, $0\le V(c)\le 1$, $v(c)>0$ and $\partial^2G/(\partial t)^2<0$, so $\text{sign}(\lambda-1)=\text{sign}(G-G_B)$, and the range of λ could be judged by the $\text{sign}(G-G_B)$.

Lemma 6: The RRF and subsidy are different with the $\text{sign}(G-G_B)$.

Proof: When $G-G_B>0$ which means that government would not only provide the budget of basic waste time but also the rest waste time, so $\lambda>1$. When $G-G_B=0$ which means that government would only provide the budget of basic waste time, so $\lambda=1$. When $G-G_B<0$ which means that budget of government would not satisfy the budget of basic waste time, so $0<\lambda<1$. And for **Proposition 2** and **Proposition 3**, **t**he RRF and subsidy should be

$$\begin{cases} F(t),S(t)>0 & \lambda>1 & G-G_B>0 \\ F(t)=S(t)=0 & \lambda=1 & G-G_B=0 \\ F(t),S(t)<0 & 0<\lambda<1 & G-G_B<0 \end{cases} \qquad \text{Q.E.D.}$$

From **Lemma 6**, the amount of government's budget is determinant of RRF and subsidy. When government want to use the economic incentives to increase the individual's use time of DRW container, government need to provide more budget, so it is hard to let RFMB self-finance under the assumption of the linear relationship between RRF and subsidy.

When government want to let RRF and subsidy are zero, it means the recycle process of DRW container is free market, if government still want to increase the individual's use time of DRW container, the improvement of the least environmental consciousness($\underline{c}$) is its determinant. In the other side, when government want to let RFMB self-finance (G=0), the optimal RRF and subsidy should reverse, this means that every individual gets subsidy on the use time of a DRW container and pays RRF on its waste time.

3.2 The model with the externality of DRW containers

This model would include the assumption and conclusion of 3.1, and assumes that the government does not know the externality of DRW containers by every individual, but know and announce the past social externality of DRW containers which is E (constant).

The individual utility which every individual gets from a DRW container is U_e, which should be reversal proportional to the past social externality of DRW containers, so 0 < $U_e = G_e(c,t,E)$ and $\partial G_e/\partial E < 0$, $\partial^2 G_e/(\partial c \partial E) < 0$, $\partial^2 G_e/(\partial t \partial E) < 0$, $\partial^2 G/(\partial E)^2 > 0$. Every individual could not observe its externality of DRW containers, but observe the past social externality of DRW containers.

The decision problem of a DRW container by individual i is to choose t to maximize its net individual utility, under the assumption of the past social externality of DRW containers, RRF and subsidy. This problem amounts to

$$\max_t W_e(c,t,E) = G_e(c,t,E) - \int_0^t H(x)dx + \int_t^T KH(x)dx \qquad (20).$$

The first order condition and the second order condition of (20) are like (2) and (3), and **Lemma 1** and **Lemma 2** stand with the first order condition and the second order condition of (20), too. Thus, even when there is externality of DRW containers, the more is the environmental consciousness of DRW containers by every individual, the more is its use time and net individual utility.

The externality of DRW containers which is the function of waste time is e(T-t(c)), and $\partial e/\partial t < 0, \partial^2 e/(\partial t)^2 > 0$, so the present social externality of DRW containers ($\phi(c)$) is $\phi(c) = N\int_{\underline{c}}^{\bar{c}} e(T - t(\tau))v(\tau)d\tau$. And government would reduce the social externality of DRW containers, so the present social externality of DRW containers should be less than or equal to its past one, so the dynamic adjustment function of the present social externality of DRW containers is $\phi'(c) = Ne(T - s(c))v(c)$, and its constraint is

$$\phi(\underline{c}) = 0, \ \ \phi(\bar{c}) \le E \qquad (21).$$

The government would choose policy variable (η) to optimize the net social utility of a DRW container under the budget constraint , (21) and the dynamic adjustment function of the use time of a DRW container, RRF, subsidy, the subsidy amount of every individual and the present social externality of DRW containers. Thus, its Hamiltonian function ($HF_e(t)$) is

$$HF_e(t) = N[G_e(c,t,E) + IS(t)]v(c) + \alpha\eta + [(\beta + K\gamma)/(K+1)]\{\eta[\partial^2 G_e/(\partial t)^2]$$

$$+ \partial^2 G_e/(\partial t \partial c)\} - \delta\eta(K+1)H(t) - \lambda NIS(t)v(c) + \pi Ne(T - t(c))v(c)$$

$$+\pi\phi(\underline{c})+\pi[\phi(\bar{c})-E]$$

when π is the multipliers of $\phi'(c)$ and (21).

Its necessary conditions are

$$\frac{\partial HF_e}{\partial E}=\begin{cases} N(\partial G_e/\partial E)v(c)+[(\beta+\gamma K)/(K+1)] & c\in[\underline{c},\bar{c}) \\ \{\eta[\partial^3 G_e/((\partial t)^2\partial E)]+\partial^3 G_e/(\partial t\partial c\partial t)\}=0 & \\ N(\partial G_e/\partial E)v(c)+[(\beta+\gamma K)/(K+1)] & c=\bar{c} \\ \{\eta[\partial^3 G_e/((\partial t)^2\partial E)]+\partial^3 G_e/(\partial t\partial c\partial t)\}-\pi=0 & \end{cases} \quad (22),$$

$$\alpha'=-\{N[\partial G_e/\partial t-(1-\lambda)(K+1)H(t)]v(c)-\delta\eta\,\partial^2 G_e/(\partial t)^2$$

$$+[(\beta+\gamma K)/(K+1)][\eta(\partial^3 G_e/(\partial t)^3)+\partial^3 G_e/(\partial t\partial c\partial t)]-\pi N(\partial e/\partial t)v(c)\} \quad (23),$$

The other necessary conditions are the same with (12) and (13), so **Proposition 1** and **Lemma 3** could be proving by the same methods.

Proposition 4: $F(t(c))=(1-\lambda)V(c)(2\eta+1)[\partial^2 G_e/(\partial t)^2]/[(K+1)v(c)]$

$+\pi(\partial e/\partial t)/(K+1)$.

Proposition 5: $S(t(c))=K(1-\lambda)V(c)(2\eta+1)[\partial^2 G_e/(\partial t)^2]/[(K+1)v(c)]$.

$+K\pi(\partial e/\partial t)/(K+1)$.

Proposition 6: $\pi=N[\partial G_e(\bar{c},t(\bar{c}),E)v(\bar{c})]<0$.

Proof: **Proposition 4**, **Proposition 5** could be proving by the same methods. For $\beta(\bar{c})=0$, $\gamma(\bar{c})=0$, $\partial G_e/\partial E<0$ and (22), so $\pi=N[\partial G_e(\bar{c},t(\bar{c}),E)v(\bar{c})]<0$. Q.E.D.

For $\pi<0$, $\partial e/\partial t<0$, and from the comparison among **Proposition 2**, **Proposition 3**, **Proposition 4**, and **Proposition 5**, so the RRF and subsidy with the externality of DRW containers would be more than they without the externality of DRW containers. In the other side, **Lemma 4** might not stand, its proof is that $\text{sign}[F(t(c))]=\text{sign}[S(t(c))]$ might not be equal to $\text{sign}(\lambda-1)$.

4. Conclusion

This study would survey the mechanism, effects and problem of waste plastic container recycling system (Four-in-One Resource Recycling Program) in Taiwan, and found that the key problem of this recycling system are the linear relationship between the resources recycle fee (RRF) and subsidy. Then this paper employs the mathematical model to analyze the optimal RRF and Subsidy, and this model try to include the assumptions about the externality of waste plastic container, environmental consciousness of individuals and the balance of budge. Results of this study suggest that under current conditions, RRF and subsidy should not be optimal. Thus, the purposes of RRF and subsidy are hardly achieved for they are not consistent with the linear relationship between RRF and subsidy, this study advice the relationship between RRF and Subsidy should be revenue decoupling.

Reference

1. Musgrave, R. A. and P. B. Musgrave (1989), “Public Finance in Theory and Practice,” McGraw – Hill, New York.

2. Newson, M. (1992), ” land, Water and Development : River Basin Systems and their Sustainable Management” , New York : Routledge.

3. Oates , W. E.， “Fiscal federalism”，Harcourt – Brace - Jovanovich，New York，1972。

4. Tophan, N..，“Local Government Economics”，pp.129-98 in R. Millward et al. ，Public Sector Economics. Harlow：Longman，1983。

Recycling Cost in Japan*

Masashi Yamamoto†, Thomas Kinnaman‡, Takayoshi Shinkuma§

July 10, 2010

Abstract

Reducing wastes and increasing recycling rates are important goals for policy makers in Japan due to scarce land and high population densities. Yet the cost structure of waste management and recycling is largely unknown despite the availability of rich yet unexplored data (e.g. see MOE (2009)) on municipal solid wastes costs and quantities. This paper estimates the marginal cost of recycling specific categories of common materials in Japan. We estimate marginal costs and explore whether cost complementarities are observed among recycled outputs.

Our results confirm that marginal cost of recycling PET is highest in a recycling activity of MSW. We also derived that all the recycling activities exhibit economies-of-scale. As for cost complementarities, we find few among recyclable materials while wastes and recyclables are highly complemented in terms of the cost. The information could prove helpful to policy makers interested in designing efficient waste management plans.

* **Preliminary draft: Please do not quote.**

† (Corresponding Author) Associate Professor, Center for Far Eastern Studies, University of Toyama, address: 3190, Gofuku, Toyama, 930-8555 JAPAN, email: myam@eco.u-toyama.ac.jp

‡ Associate Professor, Faculty of Economics, Bucknell University

§ Professor, Faculty of Economics, Kansai University

1. Introduction

Even in most industrial countries, recycling became very popular within the last 20years. For example, Kinnaman (2006) says that recycling ration in the U.S. was 10% in 1990 but it becomes 30% in 2000. In Japan, the recycling ratio is about 20% in 2008[1] while it was just 5.3% in 1990. For a country, like Japan, with a limited land area compared to its population, resource constraints are always critical. Ever since 1960s, Japanese economy has been struggling with getting input resources, such as oil and metals, using in the manufacturing process. Recently, a new constraint was added, that is, shortage of the place for dumping wastes. Another words, there are constraints not only in the ordinary economic activity (e.x. production) but also in an economic activity for the end-of-life products.

Recycling, however, has a possibility to solve these two problems. Increase in recycling ratio contributes to decrease total input of virgin materials which are imported otherwise. Since some resource-owning countries start strengthening the regulation not to export precious resources from the resource security's standpoints, to substitute domestically recycled materials for virgin materials becomes increasingly important. In addition, recycling reduces total amounts landfilled. For the small country like Japan, to save land is very important. It is obvious that unit cost for landfill is much higher in Japan than the other countries, like the U.S. and it is more difficult to construct new landfill in the small country like Japan as well.

Despite importance, it seems that recycling cost has attracted fewer researchers than waste disposal cost. As is shown in the next section, there are not so many papers analyzing recycling cost in the world. Even for Japanese case, limited studies are available. Suwa and Usui (2007), for instance, studied the *Containers and Packaging Recycling Law* in Japan but it did not focus upon the cost itself. Sasao (2004) empirically analyzed the cost but that is for landfill activity alone, not for recycling activity. Recently Hosoda and Hayashi (2010) explained how important the cross-border recycling, especially among the East Asian countries, under the resource constraint, but it was not aimed at finding recycling costs.

[1] Japanese Ministry of Environment (2009).

This paper examines the recycling cost in Japan from several different viewpoints. Because of the richness of the data we use, our analysis is more comprehensive compared to the previous studies. In so doing, we show some specific features for recycling costs.

Section 2 provides with the literature review for papers of the recycling cost. Section 3 exposits the data and the Japanese laws related to waste management. Section 4 shows a result of marginal cost analysis while section 5 develops more flexible cost function analysis in order to estimate scope economy among waste treatment activities. Finally, Section 6 concludes.

2. Literature Review

The costs of operating municipal recycling programs have been estimated by three other papers in the economics literature. Using 1992 data from a sample of 57 municipalities all located within the state of Wisconsin, Carrol (1995) estimate the cost of recycling as functions of several variables including the quantity recycled. The marginal cost of recycling is estimated to be constant, implying there are no economies of scale in recycling services. Callan and Thomas (2001) expand upon the work of Carrol by considering a larger data set of 101 municipalities all within the state of Massachusetts. Economies of scale are estimated to exist in recycling services in Massachusetts. The marginal cost of recycling is estimated by Callan and Thomas to be only $13.55. Bohm et al. (2010) use 1996 data from a random sample of municipalities across all of the United States and estimate a u-shaped marginal cost curve for recycling services. The marginal cost decreases for quantities up to 4,600 tons per year but rises for quantities above this threshold. The minimum value of marginal cost is estimated at $72.57. In a related body of literature, Criner (1995), Steuteville (1996), and Renkow and Rubin (1998) estimate the costs of municipal composting programs. Criner (1995) estimates composting is worthwhile for landfill disposal fees between $75 and $115 per ton. Renkow and Rubin (1998) examined 19 cases to find composting preferred to landfilling when disposal costs are high.

This data used for this research expands upon the literature in three important dimensions. First, the data represent a 7-year panel of all municipalities in Japan. The panel nature of the data allow for the control of unobserved variables that may vary across municipalities but not across time, and eliminate any bias that may be present in all previous cross-sectional data sets. Second the data are more recent than used in the previous literature, where data were gathered prior to 1997. Third, the data in Japan include the quantity recycled of several materials, including paper, glass, metals, plastics, and other types of materials. These data allow for the first comparison of marginal cost of recycling across individual materials. The next section describes the Japanese data in greater detail.

3. Data

First, we provide a quick overview of Japan's waste management. The waste management in Japan has been prescribed by *Waste Disposal and Public Cleansing Law* (hereafter *Waste Management Law* for short), which was originally established in 1970. Even though it was repeatedly amended, the law targets only waste management and the recycling policies are not covered by the law and there are several other laws for recycling established in around 2000[2].

In Japan, municipal solid waste and industrial waste are rigorously separated through its whole treatment process and thus you need a license for each waste. For example, different licenses are needed if a waste treatment firm does business with both municipal solid waste (MSW) and industrial waste in a municipality. The chapter two of the *Waste Management Law* defines the difference between MSW and industrial waste, and the chapter four of the law explicitly states that each municipality has a responsibility for MSW generated in its region. Therefore, waste management policies for MSW widely differ in each municipality. As a result, you need two different licenses from each municipality even if you do business with only MSW but in two different municipalities.

The data we are using in this paper can be found in Ministry of Environment (2008) and are collected by each municipality who is responsible in its MSW under the supervision of the Ministry of Environment (MOE). Table 3-1 shows the descriptive statistics of the selected variables from the data.

<<< Insert Table 3-1 around here >>>

The data gathering process is organized by MOE and the result of the survey has

[2] Namely, *Law for the Promotion of Effective Utilization of Resources*, *Container and Packaging Recycling Law*, *Home Appliance Recycling Law*, *Construction Material Recycling Law*, *Food Recycling Law* and *End-of-Life Vehicles Recycling Law*. See Figure 3-1 for details.

been public since 1979. The Ministry sends a spreadsheet specifically designed for gathering MSW data to all the municipalities in Japan every year. Each municipality submits its spreadsheet to the prefecture[3] it belongs to and each prefecture aggregates the data in their region and reports it to the Ministry. The final report for the data organized by the Ministry is usually disclosed to the public one year later.

<<< Insert Figure 3-1 around here >>>

The spreadsheet consists of three different questionnaires. One is to ask physical numbers of waste treatment. It contains the volume of waste emission, incineration, recycling rate and so on. Other one is to ask the expenditure for waste disposal and recycling. It has detailed data for construction cost, wage payment, consignment, cost of landfill, etc. Finally, the questionnaire also asks how many equipment (e.g. number of trucks) each municipality has for waste treatment.

Since the questions are so many in the questionnaire, there are more than 30 spreadsheets to answer for public officer of a municipality. These data are gathered and reorganized by a prefecture level, and finally the Ministry bundles together with some analytical comment[4].

Figure 3-2 shows the trend of the municipal solid waste generation since 1998 to 2007. In Japan, total of about 50 million tons of MSW was generated in 2007 and it tends to be though gradually decreasing since 2001. It is consistent to the timing that Japanese government introduced the *Fundamental Plan for Establishing a Sound Material –Cycle Society* in 2000. After the plan, the concept of 3R (reduce, reuse and recycling) became much popular in Japanese society.

<<< Insert Figure 3-2 around here >>>

The municipal solid waste is categorized into two parts, refuse and human waste. The refuse is also divided into two categories, namely household-generated refuse and business-generated refuse. The former is largely the waste generated in each household whereas the latter is originated from small offices, convenience stores or restaurants. In

[3] Note that the local government system in Japan is a double layered. There are currently 47 prefectures and over 1,700 municipalities in Japan.

[4] The final version of this survey (only in Japanese) is available at the Ministry's web site.

Figure 3-3, per capita ratios of these two MSWs are shown by the size of population. Not only total amount of MSW but also the ratio of business-generated refuse decreases as population increases

<<< Insert Figure 3-3 around here >>>

<<< Insert Figure 3-4 around here >>>

Figure 3-4 indicates the amount of recycling material and the recycling ratio against refuse generation. As you can see in the Figure, the recycling activity is getting larger and larger since 1998. Note that, in the Figure, civic recycling means that people in a community voluntarily collects recycling materials and convey them to the public recycling firm. This custom has an old story. It has been continued more than several decades ago and becomes nonnegligible amounts in total recycling materials. The recycling rate is also getting higher and higher. In public recycling, paper has the highest percentage among recyclables and it is about one third. While paper is also the leading recycled material in civic recycling, it accounts for much larger share (over 70%) in all the recycled materials.

Figure 3-5 is the change in the landfill amount. As you expected, the number has been decreasing. Especially for direct landfill, it became less than one third in 2007 compared to 1998.

<<< Insert Figure 3-5 around here >>>

4. The Marginal Cost of Recycling Quantities

Let $Totalvcost_{it}$ denote the total annual cost of collecting, incinerating, and disposing waste materials plus the cost of collecting and processing recyclable materials in municipality i in year t. Define $incineration_{it}$ and $rectot_{it}$ as the quantity of waste and recyclable material collected, respectively, in municipality i at time t. A flexible functional form for estimating costs as a function of quantities of waste and recycling is given by

$$\text{Totalvcost}_{it} = \alpha + \gamma_i + \beta_1 \ln(\text{incineration}_{it}) + \beta_2[\ln(\text{incineration}_{it})]^2 + \beta_3 \ln(\text{rectot}_{it}) + \beta_4[\ln(\text{rectot}_{it})]^2 + \beta_5 \text{sortnum}_{it} + \beta_5 \text{wage}_{it} + \mu_{it}$$

Where μ_{it} has mean zero and variance σ^2_μ. The fixed effect estimator eliminates the effect of any unobservable variables that might vary across municipalities but are constant across time (γ_i). Results from this regression appear in Table 4-1.

<<< Insert Table 4-1 around here >>>

All variables are significant at the 1% level. The estimated coefficients can be applied to estimate the marginal cost of recycling and waste disposal. The marginal cost is positive but is estimated to decrease throughout the recycling quantities observed in the sample. That marginal cost decreases suggests returns to scale are decreasing for recycling services.

<<< Insert Figure 4-1 around here >>>

The Japanese data contain the quantity of each type of material recycled. As described above in Table 3-1, materials recycled in each community could include paper, metal, PET plastic, other forms of plastic, glass, and an assortment of "other" materials. By regressing the natural log of the total variable costs on the quantity recycled of each type of material and the quantity incinerated, we can estimate the marginal cost of recycling each material. Results from this regression are provided in Table 4-3.

<<< Insert Table 4-2 around here >>>

Not all variables are significant in this case. With coefficients of zero, as is the case with PET plastics, the marginal cost of recycling an additional unit is constant. Where the coefficient on either the log of the quantity or its squared term is positive the marginal cost of recycling the material is not estimated to be constant, as is the case with all materials except PET. The estimated marginal cost for recycling each material is provided in Figure 2. To estimate these marginal cost curves, we used the estimated coefficient in Table 3 regardless of whether the coefficient is statistically not different from zero. The quantities of all other materials and other variables in the regression are held constant at their mean levels while deriving the MC for each material.

<<< Insert Figure 4-2 around here >>>

Only plastic shows U-shaped MC, and also falls below zero. The MC of all other material decreases with the quantity recycled for all quantities in the sample.

To place the difference in costs into perspective, Table 4-3 shows the estimated marginal cost of recycling the meanth unit of each material. The most costly material to recycle is PET plastic – the estimated marginal cost of recycling the 87th ton (the sample mean is $902.31. This amount is about double the marginal cost of recycling the next most expensive unit in the sample – metal and the category of "other" materials. Glass and paper are comparatively less expensive to recycle, and the marginal cost of recycling the meanth unit of non-PET plastic is estimated to be negative.

<<< Insert Table 4-3 around here >>>

Perhaps the most interesting result in Table 4-3 is the comparison of recycling each material with the cost of incinerating the material. The marginal cost of incinerating the meanth unit is only $3.14 – a small fraction of the marginal cost of recycling nearly every other material.

5. The Affect on Marginal Cost from Changes in Quantities of Other Materials

Although previous literatures rarely pay attention to it, a waste treatment service has a multi-product feature. It `produces' not only waste disposal but also some recycling materials out of paper or glass, and landfill. In this section, we examine how these outputs are related each other in terms of total cost of recycling. In other words, we explore if there are cost complementaries among recycled outputs by estimating a cost function in highly flexible manner.

We adopt a translog cost function for the purpose above. A translog function is one of the most popular functional forms in so – called flexible functions. There is a long history for estimation of a translog cost function. It was first (analytically) derived by

Christensen et. al (1973) and since then often used to check whether a particular industry has a scale economy. Christensen and Greene (1976), in which the U.S. power generator was targeted, was one of the earliest empirical studies in this topic.

Extending a single output cost function into a multi-product cost function was done by Panzar and Willig (1977) and the following analytical results were summarized in Baumol et. al (1988). In the field of waste treatment service, Palmer et. al (1997) studied the cost structure of MSW with a mulit-product specification but its result was basically based on a simulation with some hypothetical data. The present paper is most similar to Callan and Thomas (2001) who figured out cost complementarities between waste disposal and recycling through an empirical analysis although they use limited data to estimate recycling costs in the United States. Our analysis below uses the data set containing all the municipalities' statistics in Japan. This gave us more than 10,000 samples for various information for recyclables and wastes. Its variety unable us to consider the cost complementarities among seven different outputs while Callan and Thomas (2001) examined between aggregated amount of recycling and waste treatment.

5.1 The Model

Consider that each municipality is trying to minimize its cost of waste treatment service.

$$\min_{l} \; w_l l + f$$

$$\text{s.t. } F\left(I,\ \sum_i R_i,\ L,\ l,\ f\right) = 0$$

$$\overline{W} = I + R_{pa} + R_m + R_g + R_{pet} + R_{pl} + R_o + L \qquad (1)$$

:wage, :labour, :fixed cost, : wastes generated,

: Intermediate treatment (e.x. Incineration), : Landfill

: recycled material (paper, metal, glass, PET, plastics, others)

In (1), $F(\cdot)$ means an implicit production function and we have multi-products from waste treatment service industry. Then FOCs are as follows.

$$w_i - \lambda F_l = 0$$

$$F\left(\overline{W} - \sum_i R_i - L,\ \sum_i R_i,\ L,\ l,\ F\right) = 0 \qquad (2)$$

Suppose that a municipality' decision making is based on a very short period and we can ignore a fixed cost, f. By using (1), we can derive a total (variable) cost function as follows.

$$TC = l\left(\overline{W},\, w_l\, \sum_i {}_i\right) \qquad (3)$$

To estimate (3) as flexible as possible, we use the Translog Model (a second-order Taylor series expansion). Without the loss of generality, we can transform (3) as a function of the logarithms.

$$\ln TC = l\left(\ln \overline{W},\, \ln w_l\, \sum_i {}_i\right) \qquad (4)$$

Just for notational ease, we replace all the variables in (4) by $x = [x_1,\ x_2, \cdots,\ x_k]$. Then,

$$\ln TC = l(\ln x_1, \cdots,\ \ln x_k) \qquad (5)$$

Expanding this function in a second-order Taylor series around the point $x_i = 1,\ \forall i$ (so that the log of each variable is a convenient zero), we can get the following approximation.

$$\ln TC = \alpha + \sum_i \beta_i \ln x_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln x_i \ln x_j + \varepsilon. \qquad (6)$$

Greek letters are coefficients. This can be estimated by the usual OLS method. More precisely, we do panel data analysis for (6) with data described below.

5.2 Data and Estimation

5.2.1. Data

As is mentioned in previous section, our data is based on MOE(2009) which contains the annual data of municipal solid waste treatment (including recycling and landfill) in all the municipalities in Japan. We use data from 2001 to 2007. There were 3,222 municipalities in 2001 but were only 1,793 in 2007 because of extensive mergers. Thus panel dataset is unbalanced[5].

[5] We consider a mergerd municipality as a new municipality only when a new ID code is assigned to a new municipality. Note that average life time for a municipality is 4.7.

Table 3-1 shows descriptive statistics for the data we used. First, totalvcost means total waste treatment cost in a municipality. It does not include any construction cost but does include collection cost in addition to disposing cost and recycling cost. Wage is derived by dividing total personnel cost in a year by the number of workers. Totalwaste denotes all the amount of municipal solid waste generated in a municipality in one year. Rectotal means the amount recycled from the waste. We can specify in what type of recycled materials each municipality does recycling (Paper, Metal, Glass, Pet, Plastics and others). Finally, landfill is the amount of waste put into landfill.

5.2.2 Estimation

We assume that a municipality is trying to minimize total cost of waste treatment. From our specification explained in the previous section, we derive the following translog cost function.

$$\ln TC_{mt} = \alpha + \alpha_m + \sum_i \beta_i \ln x_{imt} + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln x_{imt} \ln x_{jmt} + \varepsilon_{mt}. \tag{7}$$

Here, is a subscript for municipality, and for year. In the equation above, x_{imt} means the *i*th dependent variables of *m*th municipality in year *t*. Note that the Greek letters are parameters to be estimated.

The estimation result is in Table 5-1. Since we have a panel dataset, our estimation is based on panel data analysis and Hausman test rejects random effect model. So we show the estimation result of fixed effect model in Table 5-1. In Table 5-1, a cross variable are shown in writing two variables in a row. For instance, WastePet means the parameter of dependent variable over waste $\times$ Pet. We also adopt the year dummy variables for the first six years.

Since We have many no answered municipalities for Wage and some other variable as well, our sample in Table 5-1 is 10,312. When we look at Table 5-1, we can see that the variables are significant for the most part. The adjusted R square is about 0.44 which is good enough for this kind of empirical analysis.

<<< Insert Table 5-1 around here >>>

5.3. Policy Indicators

5.3.1. Economy of scale

First, we examine whether there is economy of scale in Japanese recycling manufacturing. According to Baumol et. al (1988), Scale economies are often defined to be present when a -fold *proportionate* increase in every input quantity yields a -fold in output, where $k' > k > 1$. The degree of scale economies is the elasticity of output, ε_{Q_i}.

$$\varepsilon_{Q_i} = \frac{dTC/TC}{dQ_i/Q_i} = \frac{\partial \ln TC}{\partial \ln Q_i}$$
$$= \hat{\beta}_i + \frac{1}{2}\sum_j \hat{\gamma}_{ij} \ln x_j \qquad (8)$$

If ε_Q is smaller than 1, then there is a scale economy.

Table 5-2 is the results for ε_Q in our estimation. It says all the recycling activities show economy of scale. Economy of scale happens when the average cost function is decreasing at the current production level. Thus increasing the recycling level surely decreases the unit cost of recycling activity.

<<< Insert Table 5-2 around here >>>

Comparing the results in Table 5-2 to Callan and Thomas (2001) in which they showed ε_Q for aggregated recycling is 0.272[6], we can conclude that the magnitude of scale economy is much higher in Japan.

5.3.2. Cost Complementarities

Next, we check interaction among recycling of different products by using an indicator called cost complementarities. Baumol et. al (1988) defines weak cost complementarities as follows. ``A twice-differentiable multi-product cost function exhibits *weak cost complementarities*, if

$$\frac{\partial^2 TC(Q_i,Q_j)}{\partial Q_i \, \partial Q_j} \leq 0 \qquad (9)$$

with the inequality holding strictly over a set of nonzero measure.''. The presence of weak

[6] It is shown in Table 3 (p.556) in Callan and Thomas (2001).

cost complementarities implies that the MC of producing one product decreases with increases in the quantities of all other products. Weak cost complementarities are a sufficient condition for economies of scope.

In Table 5-3, we summarize the cost complementarities among recyclables with other waste treatment activities. Note that Table above is symmetric from its definition. From Table 5-3, we can say that increases in all the recyclables except plastics reduce the cost of landfill while increase in emission of the waste increases the cost of landfill.

Focusing on the results among recyclables, we have different signs are derived from the estimates of the cost complementarities. Only combination of recyclables which has cost complementarities with significance is PET and Glass while most of other combinations has the positive signs with significance.

<<< Insert Table 5-3 around here >>>

Callan and Thomas (2001) discusses that there is a scope economy between the disposal service and recycling. They say ``the cost of providing recycling services plus the cost of providing disposal services is approximately 5% higher than the joint cost of providing both services." In our estimation, the cost of providing landfill decreases when most recycling activities increase. Although it is very difficult to consider these complementarity effects among MSW services beforehand, this true cost and benefit of recycling activity should be emphasized when each municipality develops MSW management planning since there is limited land area to dispose of in Japan.

6. Policy Implications and Conclusions

Our analysis in Section 4 shows that recycling activity is incredibly costly compared to other waste treatment, like incineration. This means it is rational not to do recycling if a municipality single-mindedly depends on this marginal cost analysis. Indeed, Table 5-2 suggests that the average costs of each recycling activity decreases if we increase the total amounts of recycling. The point is, however, that each municipality cannot control the amount of the waste generated, namely in (1).

One way to decrease the cost of recycling is to give up too rigorous discrimination between municipal solid waste and industrial waste prescribed by the *Waste Management Law* in Japan. As we explain in Section 3, under the *Waste Management Law* in Japan, a waste generator is in charge of disposing of its industrial waste while it is a municipality who has a responsibility for municipal solid waste. For example, a used-paper recycling plant for municipal solid waste, in principle, cannot accept any used-paper generated as industrial waste, and vice versa. Even though these two bundles of the used paper become recyclables through exactly the same recycling process, these two cannot be recycled in the same plant because of the difference who generates it.

It is rational from an economic perspective if industrial waste is recycled because a generator of industrial waste, who is usually a private firm, does not recycle if there is any waste treatment method cheaper than recycling. According to the Japanese Ministry of Environment, the recycling rate of industrial waste in Japan is 52%[7], which is much higher than municipal solid waste.

How come the industrial waste recycling is economically rational? There are two reasons for it. One is that waste from industrial process is much more homogenous because each manufacturer in general makes the homogenous product a lot. As a result, the wastes also become homogenous. It is clear that the total recycling cost becomes smaller if the sorting process is not needed. The other reason is that the total amount of the industrial waste is about eight times larger than that of municipal solid waste[8]. Based on our analysis in Section 5, the average recycling cost of industrial waste is cheaper than the municipal solid waste.

From the first reason above, we can conclude that effort for the proper sorting by each household contributes to reduce recycling cost. But it is far beyond what a policy maker can influence. Rather we would like to emphasize the second reason. It seems that the recycling process in industrial waste has enough size to use up a scale economy. If a policy maker stops discerning industrial wastes and municipal solid wastes only for recycling process, municipal solid waste recycling, which has strong scale economy property, could enjoy drastic cost reduction. Since Table 5-3 confirms that there are cost complementarities among each recycling activity and landfill, this policy reform leads to the extension of landfill life time as well. Note that this reform, to amend the *Waste Management Law* a little bit, could be implemented now and is significantly helpful for

[7] See the website of MOE for detail: http://www.env.go.jp/recycle/waste/sangyo/sangyo_h19a.pdf
[8] Ibid.

most of more than 1,700 municipalities in Japan.

References

Baumol, William J., Panzar, John C. and Robert D. Willig (1988) *Contestable Markets and the Theory of Industry Structure*, revised edition, Academic Press.

Bohm, Robert A., David H. Folz, Thomas C. Kinnaman and Michael J. Podolsky (2010) "The Costs of Municipal Curbside Recycling and Waste Collection." Forthcoming in *Resources, Conservation, and Recycling*.

Callan, Scott J. and Janet M. Thomas (2001) `` Economies of Scale and Scope: A Cost Analysis of Municipal Solid Waste Services, " *Land Economics*, vol. 77(4), pp.548-560.

Carroll, W. (1995) "The Organization and Efficiency of Residential Recycling Services", *Eastern Economic Journal*, 21(2): 215-225.

Christensen, Laurits R. and W. H. Greene (1976) `` Economies of Scale in U.S. Power Generation," *Journal of Political Economy*, vol. 84, pp. 655-76.

Christensen, Laurits R., Jorgenson D.W. and L. J. Lau (1973) ``Transcendental Logarithmic Production Frontiers," *Review of Economics and Statistics*, vol. 55, pp. 28-45.

Clean Japan Center (2007) *Waste Management and 3R (Reduce, Reuse, Recycle) Policies: Japan 2007.* [9]

Criner, G., A. Kezis, and J. O'Connor (1995) "Regional Composting of Waste Paper and Food", *BioCycle*, 36(1): 66-67.

Hosoda, Eiji and Takamasa Hayashi (2010) `` A Cross –border Recycling System in Asia under the Resource and Environmental Constraints: A challenging project by the city of Kitakyushu and the city of Tianjin, *Sustainable Science*, forthcoming.

Japanese Ministry of Environment (2009) *State of Discharge and Treatment of Municipal Solid Waste* (each year).

Kinnaman, Thomas (2006) `Examining the Justification for Residential Recycling,' *Journal of Economic Perspectives*, vol. 20, pp. 219 – 232.

Palmer, Karen, Sigman, Hilary and Margaret Walls (1997) ``The Cost of Reducing Municipal Solid Waste," *Journal of Environmental Economics and Management*, vol.

9 Available online at http://www.cjc.or.jp/modules/incontent/waste2007.pdf

33, pp. 128-150.

Panzar, John C. and Robert D. Willig (1977) `` Economies of Scale in Multi-Output Production, *Quarterly Journal of Economics*, vol. 91(3), pp.481-493.

Renkow, M. and A.R. Rubin. 1998. "Does municipal solid waste composting make economic sense?" *Journal of Environmental Management*, 53(4): 339-347.

Sasao,Toshiaki (2004) ``An estimation of the social costs of landfill siting using a choice experiment," *Waste Management*, vol.24, issue 8, pp.753-762.

Steuteville, R. (1996) "How Much Does it Cost to Compost Yard Trimmings?" *BioCycle*, 37(9): 39-43.

Suwa, Tatsuo and Takehiro Usui (2007) "Estimation of Garbage Reduction and Recycling Promotion under the Containers and Packaging Recycling Law and Garbage Pricing," *Environmental Economics and Policy Studies*, 8(3), 239-254.

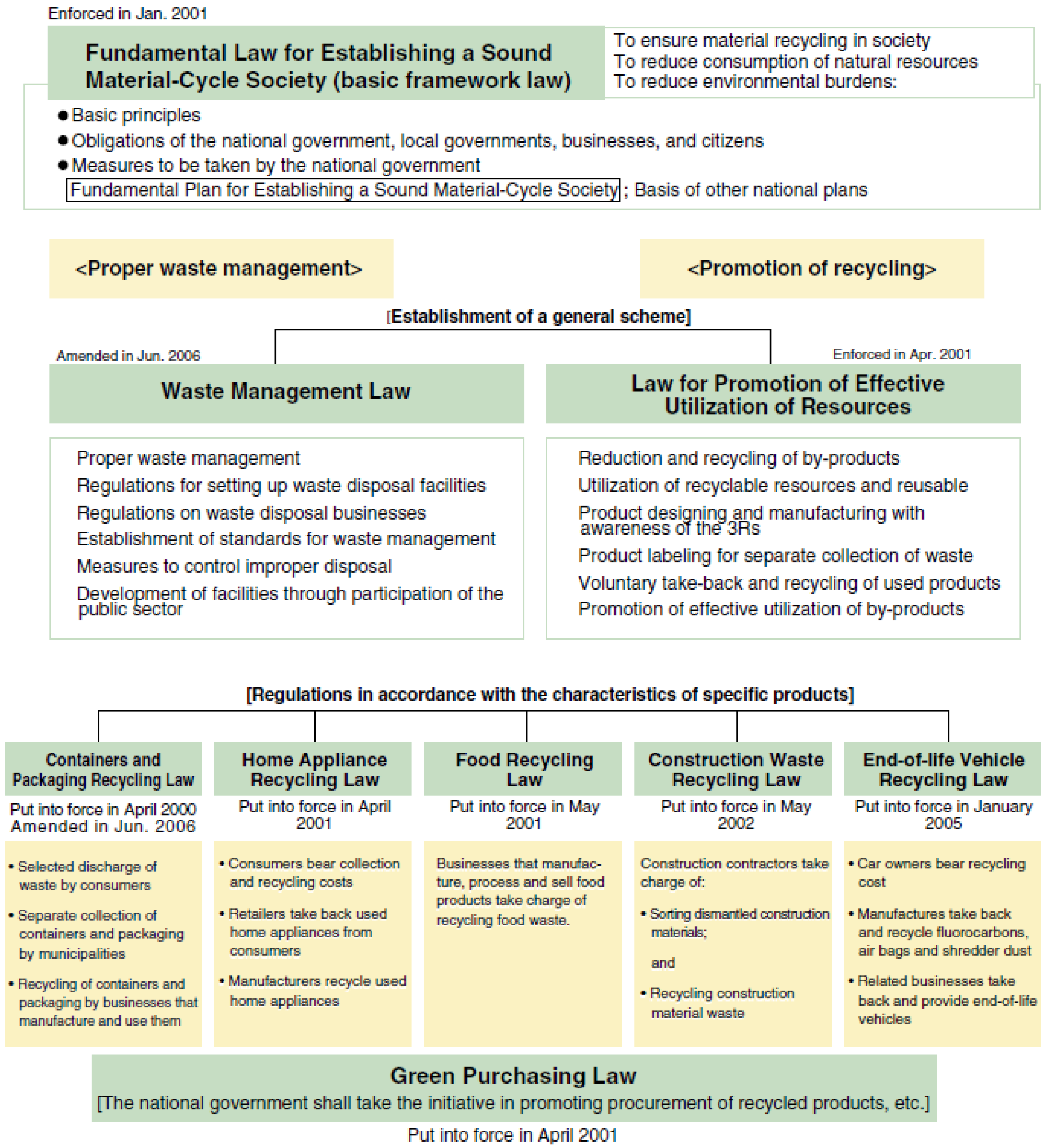
Table 3-1: Definition of Variables

VARIABLE NAME: Definition

	MEAN	MIN	MAX	N
Population: Number of persons in each city				
	47,713	194	3,649,028	17501
Totalwaste: Annual tons of waste collected in city				
	19,106	31	1,744,551	17501
Rec: Percentage of Totalwaste that is recycled				
	20.72	0	100	17498
Landfill: Annual tons of waste disposed in landfills (the remainder is incinerated)				
	2,935	1	353812	17253
Sortnum: Number of materials sorted for recycling				
	10.75	1	26	17496
Wasteh: Annual total waste collected from households				
	12,464	0	981812	17501
Wasteb: Annual total waste collected from businesses				
	6,134	0	1022470	17448
Rectotal: Annual tons of total materials recycled				
	3,523	0	362,881	17501
Rpaper: Annual tons of paper recycled				
	1,845	0	224,295	17501
Rmetal: Annual tons of metals recycled				
	486	0	25,330	17501
Rglass: Annual tons of glass recycled				
	332	0	23028	17501
Rpet: Annual tons of PET plastics recycled				
	87	0	12,238	17501
Rplastic: Annuals tons of other plastics recycled				
	196	0	47,411	17501
Rothers: Annual tons of other materials				
	578	0	122,129	17501
Vcost1: Variable cost paid by municipality				
	444,562	0	5.77e+07	17500
Vcost2: Variable cost paid by KUMIAI[10]				
	93,868	0	2,535,172	17500
Totalvcost: Vcost1 + Vcost2 (thousand Yen)				
	538,430	0	5.77e+07	17500
Personnel cost: Total annual Personnel cost (thousand Yen)				
	197,932	0	4.15e+07	14988
Labour: Number of workers in all the waste treatment				
	21.82	0	4,026	17501
Wage: Personnel cost divided by Labour				
	6,404	1	2801305	10485

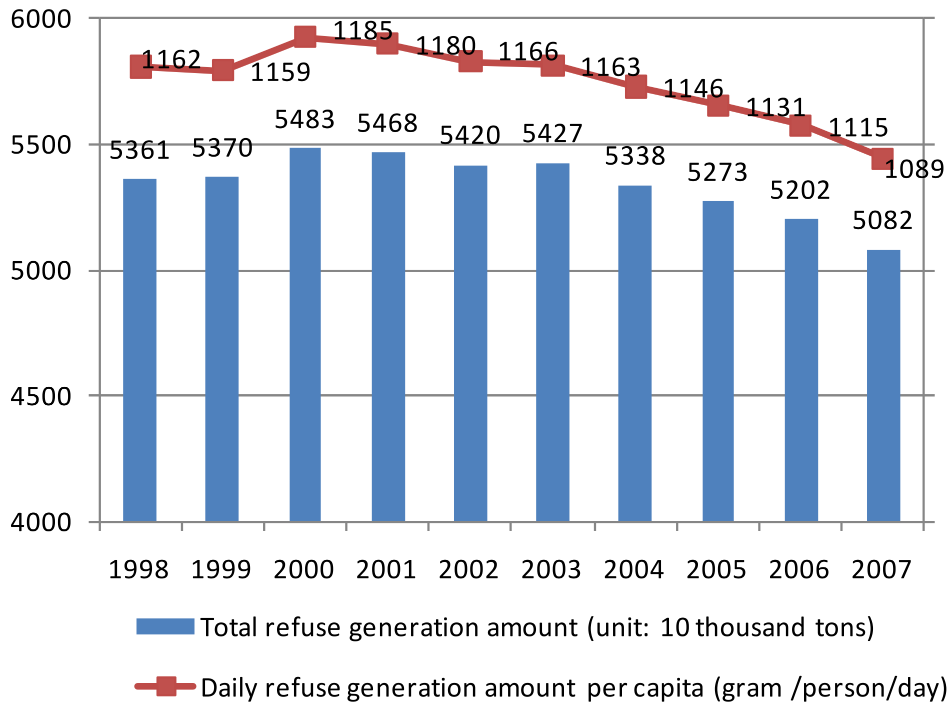
[10] KUMIAI means a public organization established by more than two of smaller municipalities. In some municipalities, they outsource part of their waste treatment since the municipalities are too small to handle all the treatment by themselves.

Figures 3-1: Legislative System for Waste management and Recycling in Japan



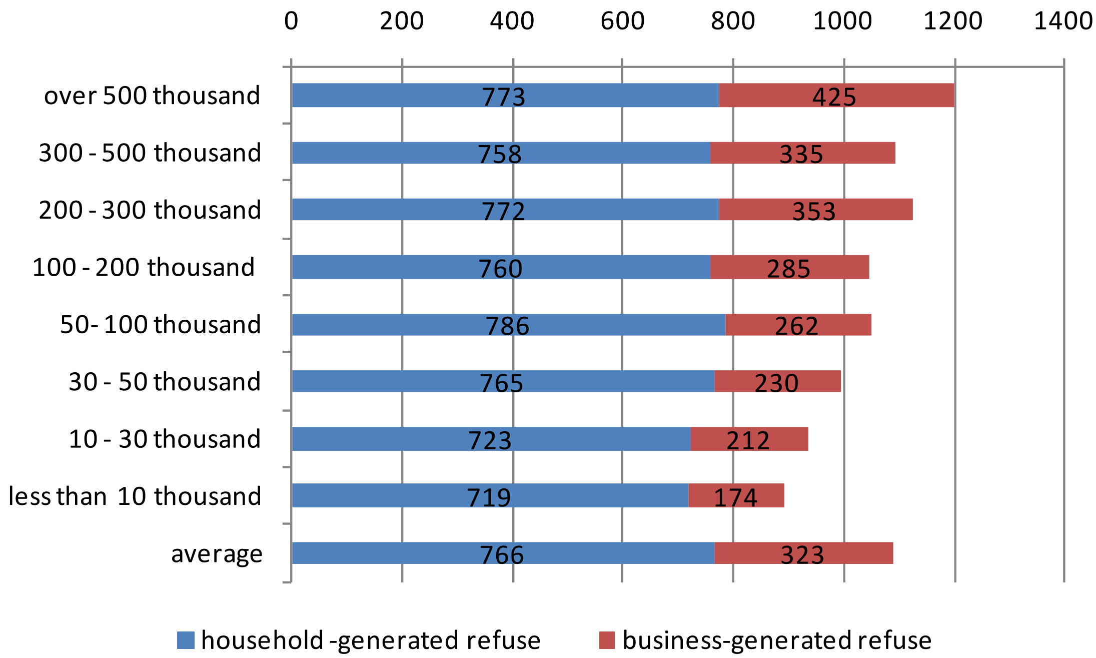
Source: Clean Japan Center (2007)

Figure 3-2: Changes in the Total Amount of Refuse Generation



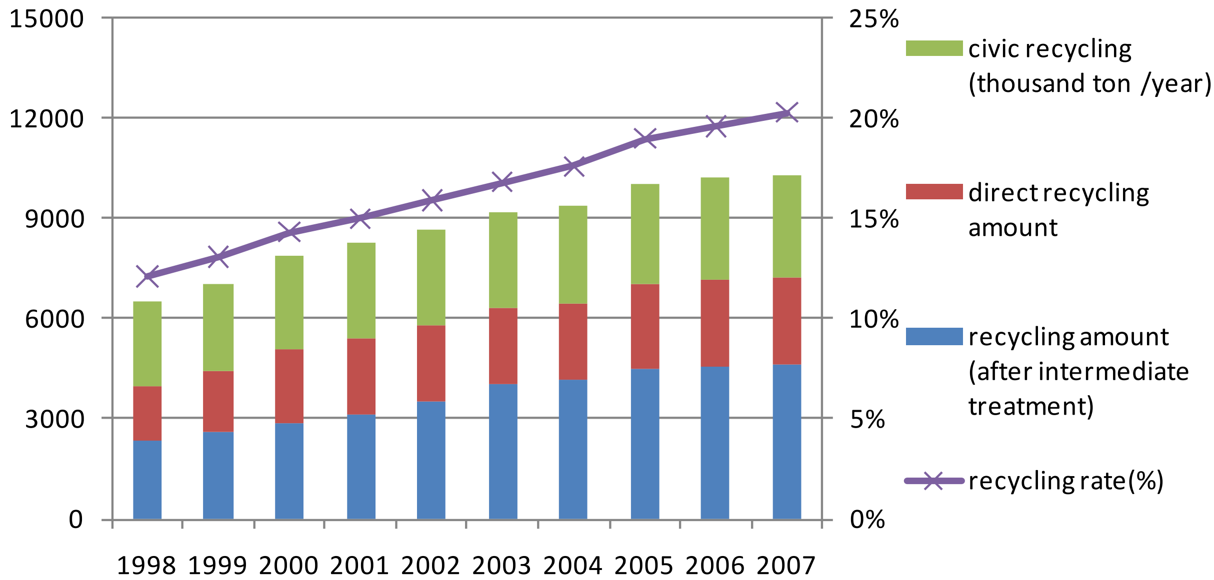
Source: MOE(2009)

Figure 3-3: Comparison of Refuse Generation per capita by Population Size



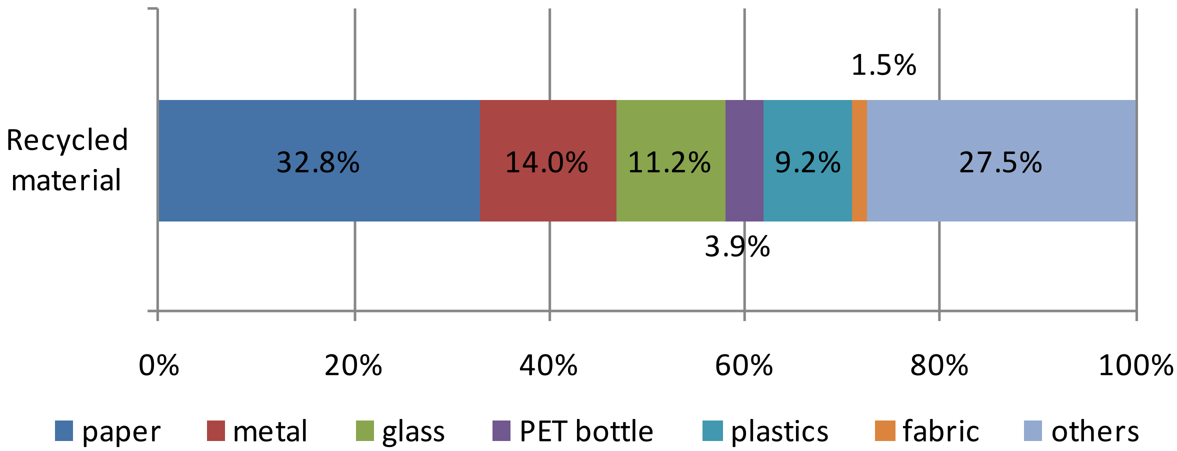
Source: MOE(2009)

Figure 3-4: Changes in Recycling Activity



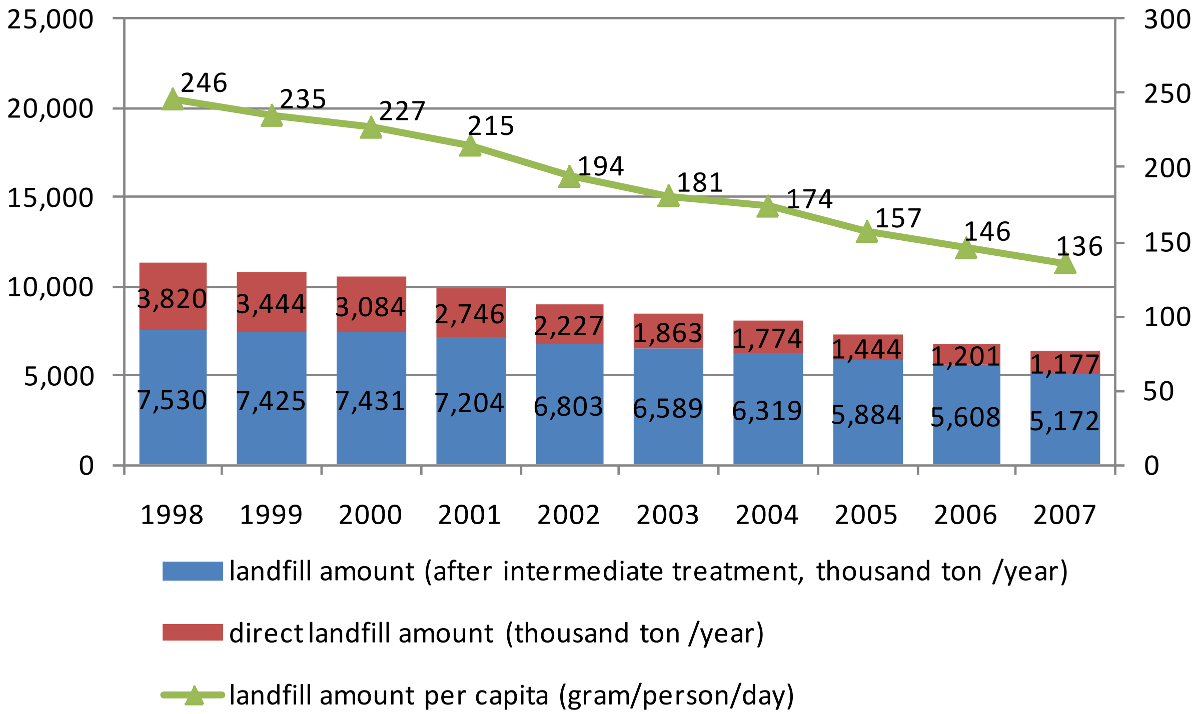
Source: MOE(2009)

Figure 3-5: Composition of Recycled Material



Source: MOE(2009)

Figure 3-6: Changes in Landfill Amount



Source: MOE(2009)

Figure 4-1: The Marginal Cost of Recycling All Materials ($US)

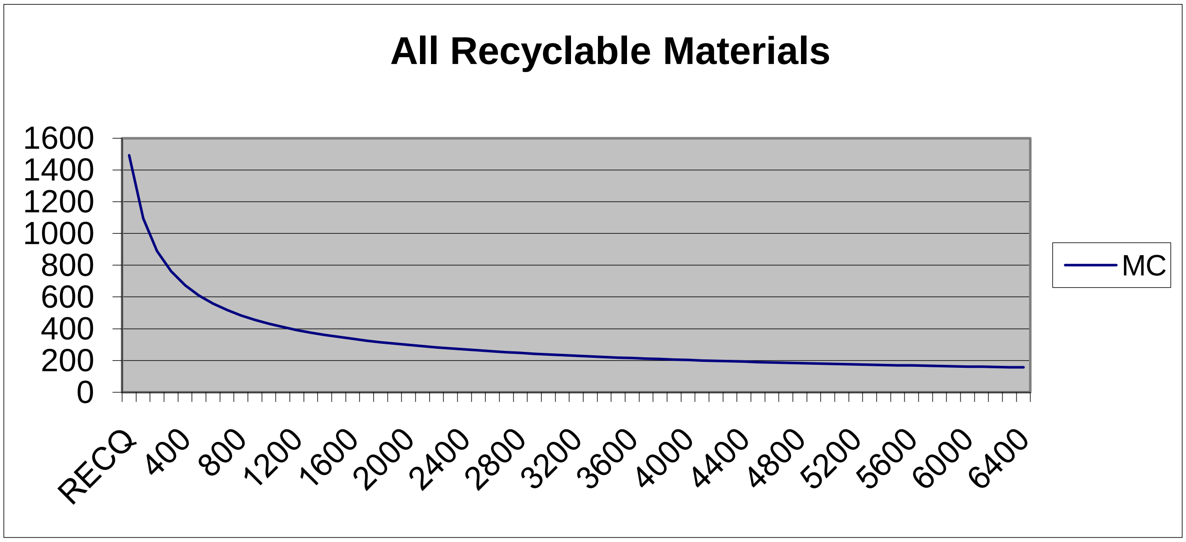


Figure 4-2: The Marginal Cost of Recycling Each Material ($US)

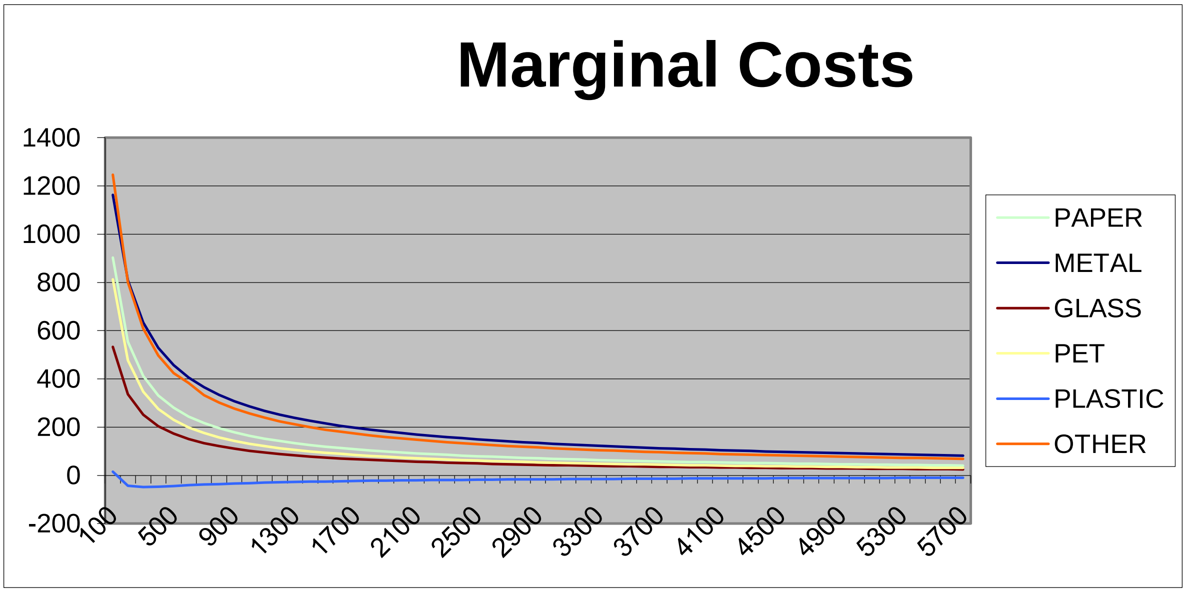


Table 4-1: The Cost of Recycling All Materials (independent variable is LN(Totalvcost))

Variable	Fixed Effects Estimate (B)	SE	Significance
LN(rectot)	-0.123	0.015	1% level
[LN(rectot)]^2	0.023	0.001	1% level
LN(incineration)	-0.067	0.010	1% level
[LN(incineration)]^2	0.010	0.001	1% level
Sortnum	0.005	0.001	1% level
Wage	1.83e-06	7.69e-08	1% level
Constant	11.849	0.058	1% level
N = 10,479, R^2 (within) = 0.154, R^2 (between) = 0.898, R^2 (overall) = 0.887			

Table 4-2: The Cost of Recycling Each Material (independent variable is LN(Totalvcost))

Variable	Fixed Effects Estimate (B)	SE	Significance
LN(rpaper)	-0.009	0.008	-
[LN(rpaper)]^2	0.004	0.001	1% level
LN(rmetal)	-0.045	0.013	1% level
[LN(rmetal)]^2	0.009	0.002	1% level
LN(rglass)	-0.010	0.010	-
[LN(rglass)]^2	0.003	0.002	10% level
LN(rpet)	-0.001	0.008	-
[LN(rpet)]^2	0.002	0.002	-
LN(rplastic)	0.019	0.005	1% level
[LN(rplastic)]^2	-0.002	0.001	5% level
LN(rother)	-0.024	0.004	1% level
[LN(rother)]^2	0.007	0.001	1% level
LN(incineration)	-0.069	0.010	1% level
[LN(incineration)]^2	0.010	0.001	1% level
Sortnum	0.005	0.001	1% level
Wage	1.83e-06	7.74e-08	1% level
Constant	11.972	0.044	1% level
N = 10,479, R^2 (within) = 0.143, R^2 (between) = 0.880, R^2 (overall) = 0.867			

Table 4-3: The Marginal Cost of Recycling the Meanth Unit ($US)

Material	Mean	MC
Paper	1845	101.44
Metal	486	465.89
Glass	332	234.36
PET	87	902.31
Plastic	196	-42.33
Other	578	382.47
Incineration	14,533	3.14

Table 5-1 Estimation Results of Translog Cost Function

Variable	Coef.		(Std. Err.)	Variable	Coef.		(Std. Err.)
Waste	0.6315	**	-0.0267	GlassGlass	0.0187	†	-0.0108
Paper	0.0675	**	-0.0106	GlassPet	-0.0199	†	-0.0107
Metal	0.0093	†	-0.0054	GlassPlastic	-0.0111		-0.0091
Glass	0.0219	**	-0.0074	GlassOthers	-0.033	**	-0.01
Pet	0.0067		-0.0084	GlassLand	-0.002		-0.0239
Plastics	0.0192	**	-0.0055	GlassWage	0.0434		-0.0368
Others	0.0459	**	-0.0049	PetPet	-0.0046		-0.007
Landfill	-0.0707	**	-0.0107	PetPlastic	-0.0023		-0.0062
Wage	0.0668	**	-0.0078	PetOthers	-0.0228	**	-0.008
WasteWaste	-0.0903		-0.0608	PetLand	-0.0283		-0.0199
WastePaper	-0.1396	**	-0.0405	PetWage	-0.1816	**	-0.0398
WasteMetal	0.0871	*	-0.0411	PlasticPlastic	-0.0059		-0.0048
WasteGlass	-0.1136	**	-0.042	PlasticOthers	0.0246	**	-0.0043
WastePet	0.0476		-0.0361	PlasticLand	0.0732	**	-0.0111
WastePlastic	-0.086	**	-0.0196	PlasticWage	0.0653	*	-0.0318
WasteOthers	0.0589	*	-0.0232	OthersOthers	-0.0044		-0.0036
WasteLand	0.3482	**	-0.057	OthersLand	-0.0318	*	-0.0124
WasteWage	-0.0507		-0.0977	OthersWage	0.1286	**	-0.0222
PaperPaper	0.0015		-0.0121	LandfillLandfill	-0.0984	**	-0.0152
PaperMetal	0.0606	**	-0.02	LandWage	0.2152	**	-0.0519
PaperGlass	0.0683	**	-0.0201	WageWage	0.0765	**	-0.0035
PaperPet	-0.0174		-0.0171	YearDummy1	-0.0016		-0.002
PaperPlastic	-0.0012		-0.0094	YearDummy2	-0.0008		-0.0019
PaperOthers	0.0382	**	-0.0117	YearDummy3	-0.0005		-0.0019
PaperLand	-0.0382		-0.0237	YearDummy4	0.0009		-0.0018
PaperWage	-0.0542		-0.0442	YearDummy5	-0.0052	**	-0.0017
MetalMetal	-0.0328	**	-0.0101	YearDummy6	-0.0069	**	-0.0017
MetalGlass	0.0465	**	-0.0164	Intercept	0.0017		-0.0034
MetalPet	0.0478	**	-0.0143				
MetalPlastic	0.0159	†	-0.0093				
MetalOthers	-0.044	**	-0.008	N=10,312			
MetalLand	-0.1199	**	-0.0217	R2=0.4434			
MetalWage	0.102	**	-0.0336	Hausman Test =0.000			
				1%: **, 5%: *, 10%: †			

Table 5-2 Economy of Scale

	Paper	Metal	Glass	Pet	Plastics	Landfill
ε_Q	0.067	0.004	0.022	0.007	0.0018	-0.075

Table 5-3: Estimation Results of Cost Complementarities

	Waste		Paper		Metal		Glass		Pet		Plastics		Landfill	
Waste	-0.05		-0.07	**	0.04	*	-0.06	**	0.02		-0.04	**	0.17	**
Paper	-0.07	**	0.00		0.03	**	0.03	**	-0.01		-0.00		-0.02	
Metal	0.04	*	0.03	**	-0.02	**	0.02	**	0.02	**	0.01	*	-0.06	**
Glass	-0.06	**	0.03	**	0.02	**	0.01	†	-0.01	†	-0.01		-0.00	
Pet	0.02		-0.01		0.02	**	-0.01	†	-0.00		-0.00		-0.01	**
Plastics	-0.04	**	-0.00		0.01	*	-0.01		-0.00		-0.00		0.04	**
Landfill	0.17	**	-0.02		-0.06	**	-0.00		-0.01		0.04	**	-0.05	**

The Green Growth Index and Policy Feedback

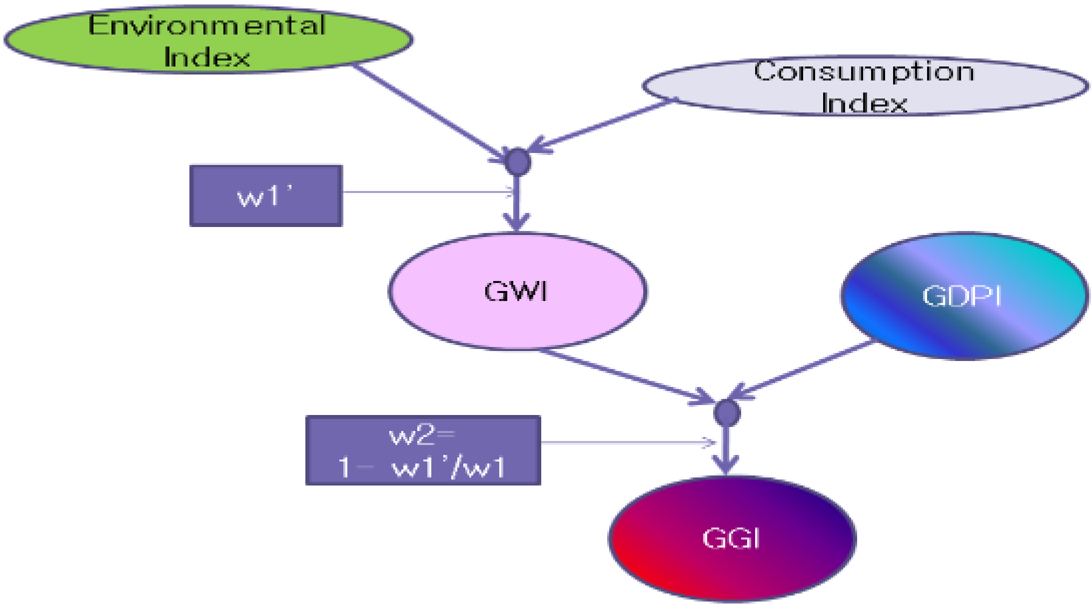
Taek-Whan Han (Seo-Kyeong University, Korea), Geum-Soo Kim (Hoeso University, Korea),
Dongsoon Lim (Dongeui University, Korea)

1. The Green Growth, the Green Growth Index, Environmental Investment, and the 'Green Growth Gap"

The green growth means an environmental-economic strategy that by sacrificing current consumption level, an economy can increase the future consumption and environmental services, and thus higher welfare level over the time. In other words, the green growth is a dynamically optimal growth path which considers environment explicitly. Here the key policy variable is the "environmental investment rate," which is the rate of all environment related investment and the cost incurred due to environmental regulations. If the "environmental investment rate" is too low or high, the economy will be deviate from the optimal growth path and will fail to attain dynamic optimum. This paper attempted to estimate the realized environmental investment rate, and at the same time, the dynamically optimal environmental investment rate. The gap between the two can be called as "green growth gap."

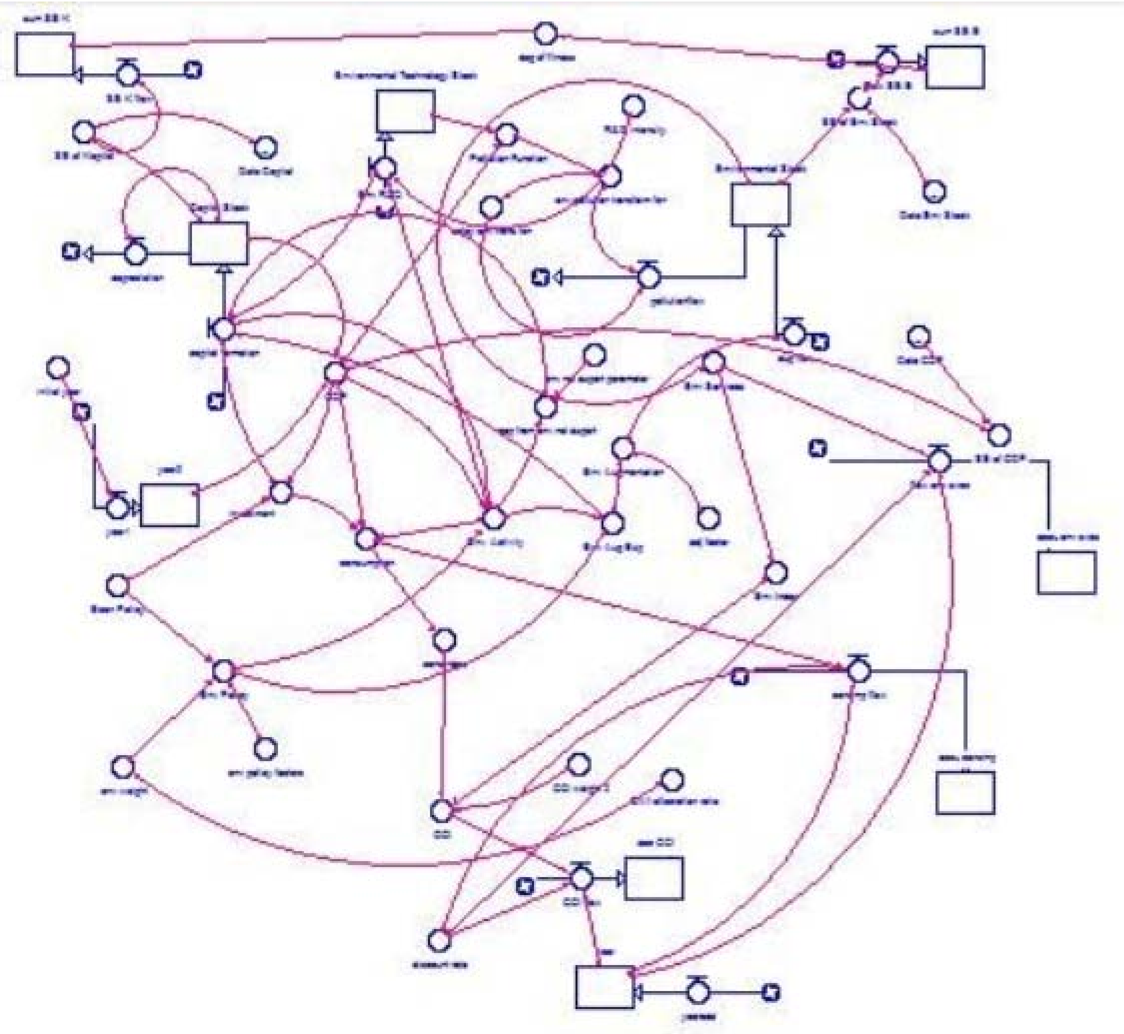
A system dynamics model is constructed to determine the weight among environmental index, consumption index, and the dynamic policy index in computing the green welfare index and the green growth index. This system dynamics model simulates dynamic growth path for the Korean economy. The model contains economic and environmental variables together. Using a system dynamics model, we compute the realized environmental investment rate. The realized environmental investment rate (w1') is determined from alternative rates that minimizes sum of squared errors between real data and simulated variable figures. The green welfare index is computed using the realized environmental investment rate as a weight between consumption index and environmental services index. The environmental investment rate that maximizes the present value of sum of future green welfare indices is estimated and called optimal environmental investment rate ($w1^*$). The normalized gap between these two rates ($1-w1'/w1^*$) is called "green growth gap." This gauges how far current growth path is deviated from the optimal dynamic path. Therefore, the green welfare index, which measures the welfare level but does not considers the optimality in a dynamic sense, needs to be adjusted using this gap. The green welfare index, when adjusted using the green growth gap, converts to the green growth index. The weight means the relative values of environmental services to the consumption. It also implies the relative weight of the part of GDP allocated to the environmental sector to the paqrt of GDP allocated to the economic sector. After computing the realized environmental investment rate, this is used as the weight to compute the green welfare index. Then the optimal environmental investment rate is estimated that maximizes

The process to compute the green growth index is shown in the following Figure 1.



2. Structure of the Model

The general equilibrium model consists of three sectors of sub-modules, economy, environment, and policy. As shown in Figure 2, economic sub-module captures interrelationship among capital stock including depreciation, capital formation, and GDP, pollution function, consumption, investment. Environmental sub-module consists of environmental stock which is determined by flow of pollution, flow of environmental augmentation (aug flow), and environmental technology stock which is determined by research and development for environmental improvement (Env R&D). In addition, pro-environmental activities (Env Activity) is also included in the module to catch the effects of environmental expenditure (Env Aug Exp) and state of environmental quality augmentation (Env Augmentation). Finally, policy module consists of economic policies (Econ Policy), environmental policies (Env Policy), and Green Welfare Index(GWI).



We allow the effects of pollution emissions from producing goods and services on the state of environment, that is, economy-to-environment path. On the contrary, we allow the effects of emission mitigation activities on the environmental industry as well as indirect feedback effects of environmental policy through Green Growth Index on the economy, that is, environment-to-economy path. Note that we restrict potential effects of environmental stock improvement on the economy such as labor productivity for simplifying modeling structure.

The performance of economic and environmental sectors are affected by changes in the policy decisions. Economic policy variable in the model is defined as the ratio of investment out of gross domestic product (GDP) in capital stock. Environmental policy variable is defined as the ratio of environmental expenditure out of gross domestic product (GDP) in capital stock. The resources that are distributed to environmental activity are divided into environmental augmentation, abatement technology innovation, general investment, and foreign sector. Environmental augmentation is referred to any mitigation of pollution emitted; abatement technology innovation, decreasing emission coefficients per production. Note that general investment in our modeling specification is regarded as capital accumulation for environmental industry, or any expenditure for complying environmental regulation in broad sense.

Resources distributed for the foreign sector, that is, net export would expand economic performance through the multiplier effect and the increased performance accordingly affects capital accumulation. In summary. the policy module consists of two categories in policy approached, economic and environmental policies. The policy effects are distributed into the economy by the shares of consumption, investment, and environmental activities out of gross domestic product (GDP). In addition, for the modeling consistency ensuring completeness and mutual exclusiveness in variables, consumption share would be automatically determined after determining the shares for investment and environmental activities.

3. Empirical Estimation of the Model

As shown in Figure 1, the dynamic model needs to identify the most suitable environmental investment ratio. The ratio can be obtained by consistent estimation of each factor and equation for the model. We estimate most parameters that describe current economic reality well, and establish systematic functional relationship with well-designed equations. We finally simulate the dynamic path of target variables to find optimal environmental investment ratio, weight for environmental activity, by changing the ratios within model. This process would find out the most suitable weight of environmental investment ratio, which is, by definition, supposed to maximize the discounted sum of social welfare.

This section explains empirical estimating equations for capital stock, environmental stock, and environmental technology stock in the model. First, capital stock is defined as in Equation (1). Furthermore, capital formation is estimated as in Equation (8). This equation represents our modeling specification, that is, capital stock as a sole producing factor.

Capital formation = investment*0.449 + Env__Activity - Env_R&D - Env_Augmentation + cap_from_env_net_export (8)

This simplification is based on the premise that labor input is stable and no change happens in labor productivity over the simulation time period. The economy produce final output, GDP, by utilizing the capital stock, based on production technology in Equation (9). We apply the year variable in order to include the effect of annual technology innovation over the period.

lnGDP=-348.5008+0.3474*ln(0.875136597*Capital_Stock)+46.9874*ln(year2) (9)

Secondly, environmental stock can be determined by pollution emission, negative impact factor, and environmental improvement activity, positive factor. Pollution emission is an inevitable by-product of production as in Equation (10).

Pollution_Function = 44.351 + 0.0001158*GDP - 0.0000456*Environmental_Technology_Stock (10)

The variable, Pollution_Function, means composite pollution emision which we compute an aggregate pollution emission of SOx, NOx, CO2 by principal component analysis (PCA). PCA involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. That is, we attempt to systematically estimate an representative compositie pollution emission, not by arithmatically averaging each pollution.
The pollution emission is also depending on abatement technology, Environmental_Technology_Sto차. Environmental_Technology_Stock can be translated as a certain level of environmental technology or competitiveness by accumulating environmental R&D. Since environmental stock is indexized, it is not possible to input the value directly into the pollution emission function as in Equation (10). Accordingly, we transform the stock as in Equation (11), which defines the relationship between pollution emission and incremental environmental quality. In addition, the incremental environmental quality has a fundctional relationship with assimilative capacity of nature or environmental state.

env_pollution_transform_fcn=exp(8.816566621-0.916511998* logn(Pollution_Function)) (11)

Environmental improvement or augmentation activities, Env_Augmentation, increase environmental stock. As shown in Eauation (13), Env_Augmentation is determined by environmental expenditure.

Env_Augmentation = logn(Env_Aug_Exp)*adj_factor (13)

Finaly, we confirm that environmental technology stock is accumulated by technological deveopment. We also do not assume depreciation environmental technology stock and so the stock is not supposed to decrease by years due to depreciation, but environmental technological development to be embodied within the stock. Note that the environmental technology stock may affect pollution emission function as an exogenous parameter.

4. Estimation of Environmental Investment Rate Using a System Dynamics Model

In order to constitute a final Green Growth Index we need first to find the environmental investment rate with the highest fitness for data, and then to take this as the weight given to an environmental performance in forming Green Growth Index. Next, we search out the environmental investment to maximize the stream of the Green Growth Indices as is calculated as in the above.
The weight (or environmental investment rate) with the highest fitness for data is interpreted as what makes the streams of capital stock or environmental stock generated by the System Dynamics Model fit for the corresponding real data the most. We will change the weight (or environmental investment rate) by a little to calculate the so-called Sum of Squared Error Ratio defined below, finally searching out the most fitting weight.

sum SE K = S ((Capital_Stock-Data_Capital)/Data_Capital)^2

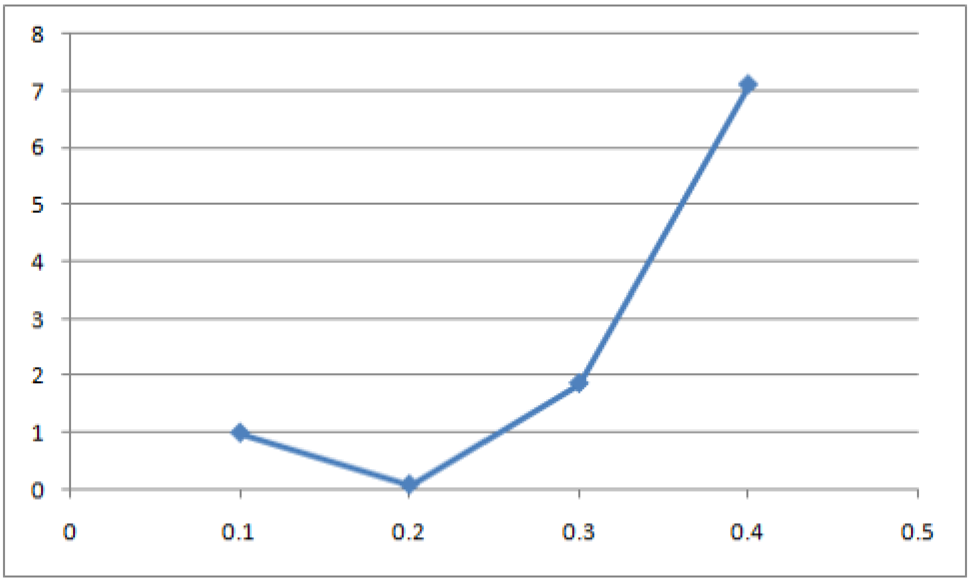
We define the so-called Degree of Fitness defined below, incorporating the Sum of Squared Erro Ratios of both capital stock and environmental stock.

deg fitness = sum_SE_E+sum_SE_K

where sum_SE_E stands for the Sum of Squared Error Ratio for environmental stock. These are all placed in the upper part of our Stellar model.

4.1. Searching out the weight with the highest degree of fitness

The following Figure 2 draws out the locus of deg fitness varying the weight (or environmental investment rate) from 0.1 to 0.4. In the diagram the horizontal axis stands for the weight, while the vertical axis represents the degree of fitness. As you can see, the degree of fitness is minimized when the weight assumes 0.2. The exact value for the degree of fitness is shown in the Table 1. The fact that the degree of fitness takes the highest value when the weight is 0.2 means that the capital stock and environmental stock generated by our model fit for the corresponding real data the most at the value of the weight. For reference, we put the model-generating and real data together when the weight is 0.2 in Figure 3. In the figure, the horizontal axis represents the number of rounds in the simulation, which in fact means each year in the period of our analysis.



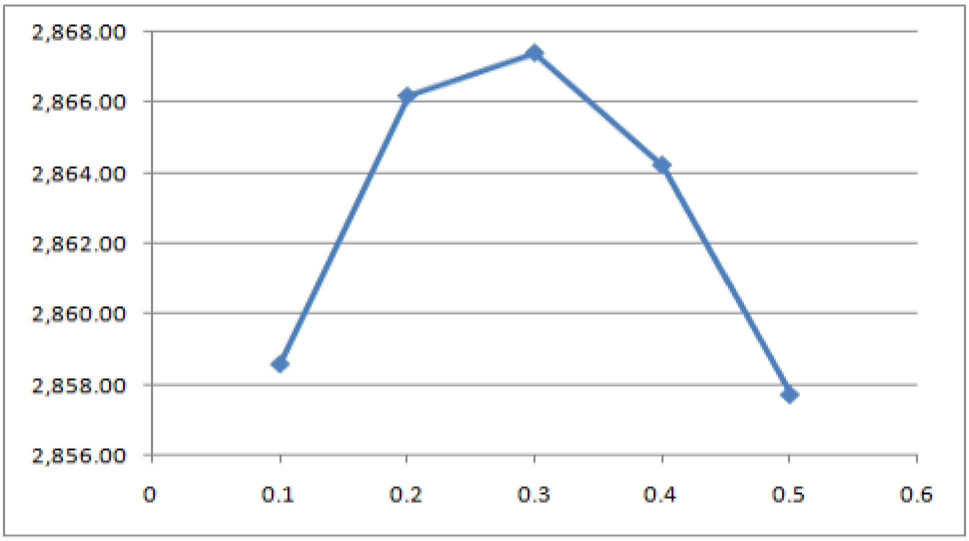
weight	0.1	0.2	0.3	0.4
degree of fitness	1	0.09	1.87	7.11

4.2. Searching out the optimal environmental investment rate

Next, with the weight for constituting Green Welfare Index fixed at 0.2 as has produced the highest degree of fitness, we search out the optimal environmental investment rate that maximizes the discounted sum of Green Welfare Indices. In Figure 4, the horizontal axis represents the investment rate allocated or imputed to the environmental sector out of GDP, while the vertical axis stands for the discounted sum of Green Welfare Indices as defined in the following.

S (GGI_weight_2*Env_Index+(1-GGI_weight_2)*consindex)/(discount_rate)^year

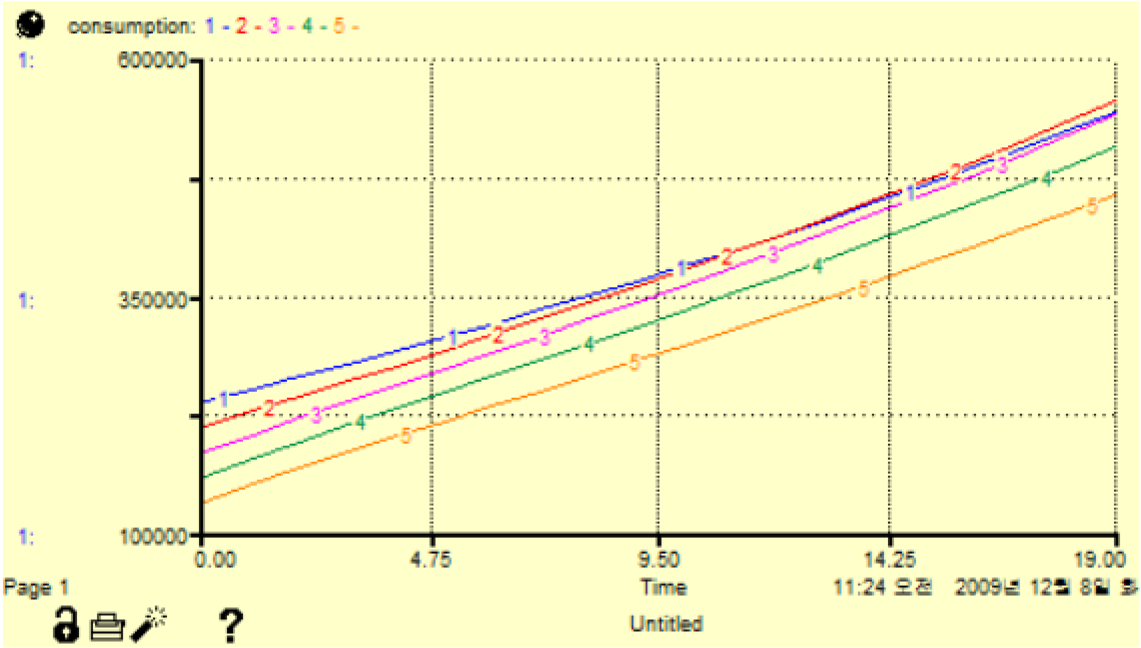
where GGI_weight_2 represents the environmental investment rate and this is used for deriving Green Welfare Index and is fixed at 0.2 as noted already. The discount_rate means a discount factor and we assume that it is 1.02.

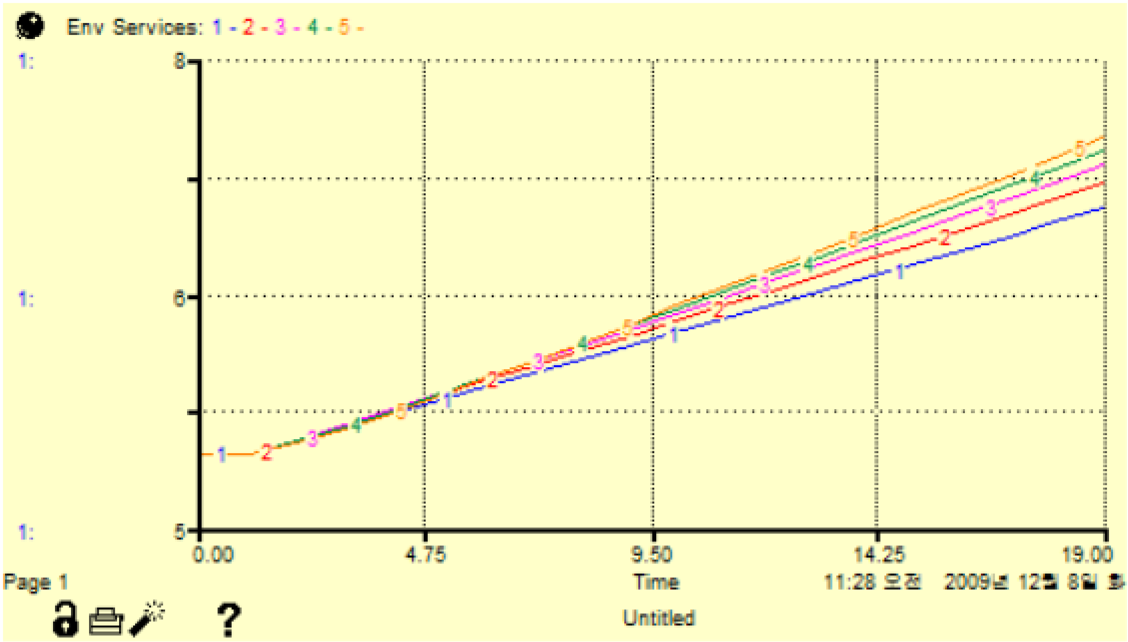


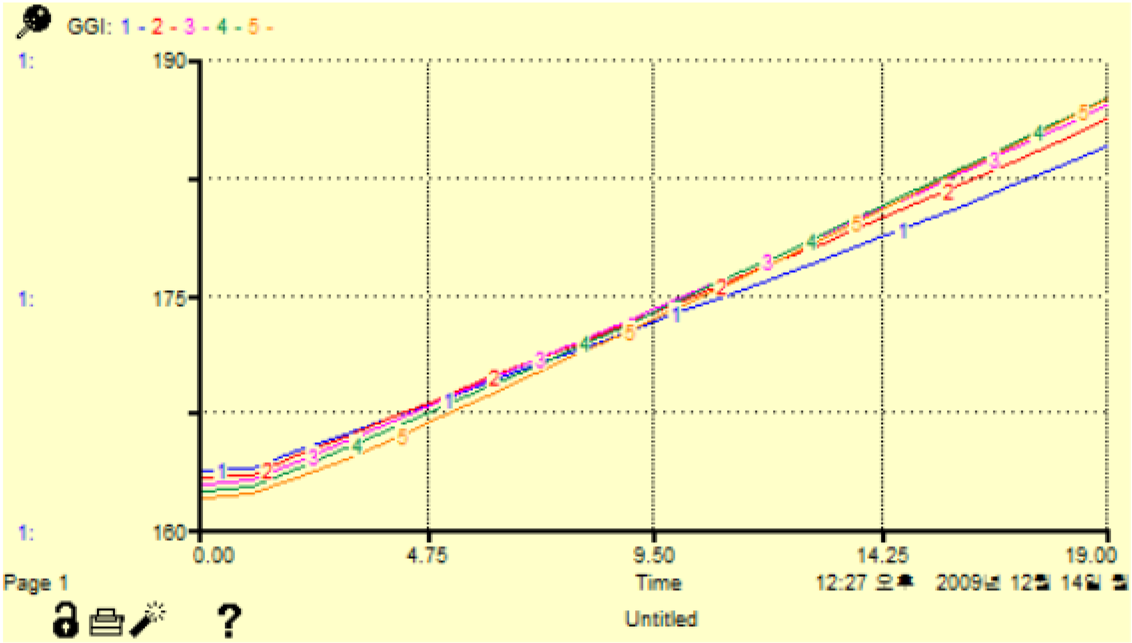
As you can see in the above figure, the discounted sum of Green Welfare Indices attains its local maximum when the environmental investment rate or imputation rate is 0.3. The value at the local maximum is 2,867.41. For reference, Table 2 shows the value at various environmental investment rate.

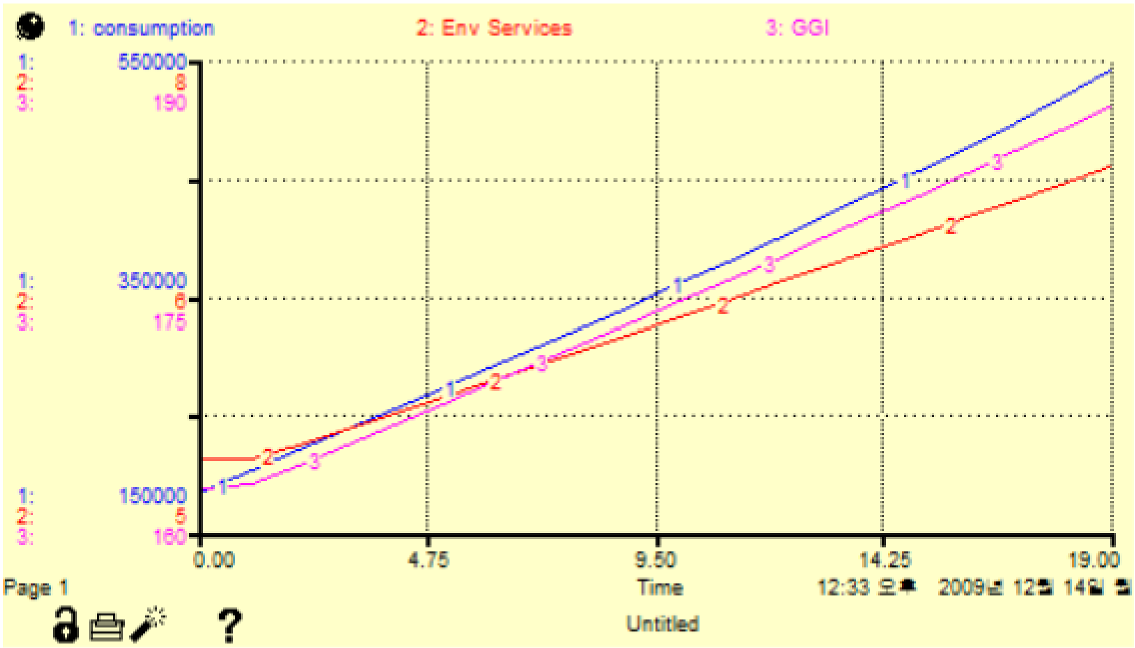
environmental investment rate	0.1	0.2	0.3	0.4	0.5
discounted sum of GWI	2,858.58	2,866.19	2,867.41	2,864.23	2,857.71

The following Figure 5, Figure 6, Figure 7 represent the locus of consumption, environmental service and Green Welfare Index, respectively as the environmental investment rate varies from 0.1 to 0.5. Lastly Figure 8 shows their loci at the optimal environmental investment rate, 0.3. One interesting observation with Figure is that the consumption changes abruptly at the turn of 0.4, while it remains about the same as the rate varies from 0.1 to 0.3. What we can observe in Figure 5 is that the environmental service doesn't change as much as the consumption, but it increases at about the constant rate. These patters have an implication for why the discounted sum of Green Growth Indices culminates in the rate, 0.3. What we can observe in Figure 6 is that as the environmental investment rate increases, the future stream of welfares increases relative to the present stream of welfares. This also gives us an hint for why the discounted sum of Green Welfare Indices is maximized at the rate, 0.3.


consumption: 1 - 2 - 3 - 4 - 5 -
600000
350000
100000
0.00
4.75
9.50
14.25
19.00
Time
Page 1
Untitled


Env Services: 1 - 2 - 3 - 4 - 5 -
8
6
5
0.00
4.75
9.50
14.25
19.00
Time
Page 1
Untitled





4.3. The green growth gap

As discussed, optimal environmental investment rate (maximizing discounted future GWI's) and realized environmental investment rate (best fitted, with best degree of fitness)) are different. This is important. If realized rate is smaller that the optimal rate, it implies that environmental investment is not enough. If these two rates are identical, then it is optimal, in other words, in the path of green growth. Therefore, these difference can be used as a measurement for the degree of deviation of the economy from the optima green growth path, which we call the "green growth gap."

In our dynamic model, w1' (realized environmental investment rate, w with best degree of fitness) is estimated as 20%, while w1* (optimal environmental investment rate, w maximizing the discounted sum of GWI's) is estimated as 30%. Thus, the green growth gap (w2 = 1-w1'/w1*) is computed as 1- 20/30 = 33.3%.

5. Conclusions and Implications

The fact that the realized environmental investment rate (0.2) and optimal environmental investment rate (0.3)are different for the Korea has important policy implications. This implies that environmental investment in Korea has been lower than optimal, thus there should be more investment in the environment. Since the environmental investment rate is lower than optimal, current level of green welfare cannot convey information on the optimality of the economy. Thus the weight of current level of welfare should be reduced in computing the green growth Index. More emphasis should be given to the investment for the future, rather than the enjoyment of the current fruit, particularly with regard to the environment. If the gap widens, this is a signal that the investment should be strengthened more.

Although this gap itself is an index and a good policy signal, we need more concrete and digestible one for policy use and public understanding, the Green Growth Index. The Green Growth Index should contain information for current welfare level and dynamic potential for future welfare level. The Index should also work as a policy signal to the government and citizens that current growth path is deviated. The computation process and the result for the Green Growth Index is not included in this paper, since it is too long and full of numbers.

References

Kim, Dohoon, T. Moon, D. Kim, System Dynamics (in Korean) , Daeyoung Press, 2001.

Kim, Seungrae, Carbon Tax as an Alternative Policy for Green Growth: Practice and Policy (in Korean) , Public Finance Forum No. 5, 2009.

Kim, Ho-Seok, et al., Linking Environmental Assessment and Sustainable Development Indicators (in Korean), Research Series No. 8, KEI (Korea Environment Institute), 2007.

SERI (Samsung Economic Research Institute), In the Beginning of Green Growth Era (in Korea), Research Paper No. 5, 2008.

Lee, Chang-Hoon, Current Status and Development of New and Renewable Energy (in Korean), National Congress Library Report, Vol 45, No. 8, pp. 31~41, 2008.

Jung, Young-Geun, "Problems in Estimating Environmental Sustainability Index (ESI) and Improvement Measures (in Korean)," National Land Research, Vol. 39, pp 51~65, 2003.

Cho, Kyoung-Yeop and Ingang Na, "GHG Mitigation Policies and Technological Innoavation (in Korean)," Korea Economic Research, Vol. 51, No. 3, pp. 263~294, 2004.

Choo, Jang-Min, et al., Improving Environmental Cooperation within North-East Asia (in Korean), Research Series No. 17, KEI (Korea Environment Institute), 2005.

Pyo, Heedong, et al., A Study for Developing Sustainability Index in Fishery (in Korean), Research Series No. 3, KMI (Korea Maritime Institute), 2000.

Ministry of Environment, White Paper for Environment 2007 (in Korean), 2008.

Aghion, P., Harris, C., Howitt, P., Vickers, J., Competition, imitation and growth with -step-by-step innovation. Review of Economic Studies 68 (3), 2001, 4670492.

Brock, W.A., Taylor, M.S., "Economic Growth and the Environment: A Review of Theory and Empirics," mimeo, 2004.

Chung, R.K., Green Growth: Opportunities for Bioenergy Development in Asia and the Pacific, ppt presentation file, UNESCAP, date unknown.

Chung. Young Keun. et al. 2004. Multi-country Comparative Analysis Based on the Environmental Efficiency. KEI Research Paper No. 7. KEI: Seoul.

CRW Group, "Ontario environment companies concerned green economic opportunity at risk, " April 20, 2009. (http:// www. newswire.ca/en/releases/archive/April2009/ 29/ c6144.html)

Fullerton, D. and S.-R. Kim, "Environmental Investment and Policy with Distortionary Taxes and Endogenous Growth," Journal of Environmental Economics and Management 56(2), 141-154, 2008.

Goulder and Schneider, "Induced technological change and the attractiveness of CO2 abatement policies," Resource and Energy Economics 21, 1999, 211-253

Gerlagh, Reyer and Michiel A. Keyzer, Efficiency of conservationist measures: an optimist viewpoint," Journal of Environmental Economics and Management 46 (2003) 310.333

Grossman, G., "Pollution and growth: what do we know?," In: Goldin, I., Winters, A. (Eds.), The Economics of Sustainable Development. Cambridge University Press, Cambridge, New York, 1995, pp. 19-46.

Hettige, H., Mani, M., Wheeler, D., "Industrial pollution in economic development: the environmental Kuznets curve revisited," Journal of Development Economics 62 (2), 2000, 445-476.

Hicks, J.R., Capital and Growth, Oxford, 1965.

Linster, Myriam, 2003. OECD Work on Environmental Indicators. OECD: Paris.

Moon, Tae Hoon., Hoi Seong Jeong, Chang Sug Park, Chang Je Cho, “Sustainable Land Use within a Limit of Environmental Carrying Capacity in the Capital Region, Korea,“ 『환경정책』 15(2), 2007. 12월

OECD, 1998. Towards Sustainable Development - Environmental Indicators. OECD:Paris.

Porter, Michael E., and Claas van der Linde, “ Toward a New Conception of the Environment-Competitiveness Relationship,“ The Journal of Economic Perspectives, Vol. 9, No. 4 (Autumn, 1995), pp. 97-118

Reyer Gerlagh, Bob and van der Zwaan, "Gross world product and consumption in a global warming model with endogenous technological change," Resource and Energy Economics 25 (2003) 35-57

Ricci, Francesco., "Channels of transmission of environmental policy to economic growth: A survey of the theory," Ecological Economics 60 (2007) 688-699.

UNCSD, 2007. Indicators of Sustainable Development: Guidelines and Methodologies, OECD: Paris.

Yale Center for Environmental Law & Policy and Center for International Earth Science Information Network (Columbia University), 2009. 2008 Environmental Performance Index.

Yale Center for Environmental Law & Policy and Center for International Earth Science Information Network (Columbia University), 2006. 2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship.

Optimal Strategies for the Surveillance and Control of Forest Pathogens

Tetsuya Horie*
Department of Applied Economics
University of Minnesota

Frances R. Homans
Department of Applied Economics
University of Minnesota

Robert G. Haight
Northern Research Station
USDA Forest Service

Robert C. Venette
Northern Research Station
USDA Forest Service

*Corresponding Author
1994 Buford Ave., 218A ClaOff
Saint Paul, MN 55108
(612)229-3955 (voice)
horie003@umn.edu

Abstract

In this paper, we develop a model of optimal surveillance and control of forest pathogens and apply it to the case of oak wilt in a region within Anoka County, Minnesota. Managers allocate limited budgets between surveillance and control activities. Furthermore, they try to determine the locations where these efforts will have the most benefit. Our model allows for a heterogeneous landscape, where grid cells are differentiated by the number of trees and the number of infected trees. We also allow for the possibility of differentiated spread rates and tree removal costs. Our results offer practical guidance to managers in charge of deciding how and where to spend limited public dollars when the goal is to reduce the number of trees newly infected by oak wilt.

1. Introduction

Invasive fungal pathogens have had widespread effects on forests and have increasingly threatened tree species nationwide. Chestnut blight virtually eliminated native chestnuts, and now Dutch elm disease and oak wilt are spreading throughout forested areas (Hansen 2008, Loo 2009). Because mature urban trees are particularly valuable to urban residents, protection of these trees from threats posed by invasive pests and pathogens is a high priority for urban foresters (Holmes *et al.* 2009). For fungal pathogens, the most effective means of controlling spread is the detection and removal of infected trees. In the case of oak wilt, for example, trees killed by oak wilt produce spores in the following spring, and these spores are a source of pathogen for new infections. However, budgets available for detection and removal are typically very limited and governments must decide how to allocate those limited funds among sites with different features. For example, should locations with low numbers of infected trees be given priority since these locations can more easily become disease-free, or should locations with low removal costs be given precedence because more diseased trees can be removed with the same budget? In addition, governments face a trade-off between search and control activities. Greater spending for surveillance enables governments to identify more infected trees, but increased surveillance limits the budget remaining for removal of infected trees.

In our paper, we focus on the relationship between optimal detection and control strategies when budgets are limited. We use models to inform decisions about sites to select for surveillance and removal of infected trees. These models provide information about cost-efficient trade-offs between detection and control activities. Moreover, they describe how and to what extent optimal site selection and the budget allocation between the surveillance and control of forest pathogens are sensitive to chosen parameter values. In building our model, we draw from the site selection literature, which is generally aimed at choosing sites to preserve for the purpose of maintaining biodiversity (e.g., Margules *et al*. 1988, Church *et al*. 1996, Stokland 1997, Ando *et al.* 1998, Polasky et al. 2001, Snyder *et al.* 2004). In our case, we are choosing sites on which to focus inspection activities in order to remove trees found to be infected. We formulate a two-stage site selection model with a budget constraint. A mixed integer formulation allows us to solve the model by determining the level of treatment intensities as well as selecting sites for surveillance and treatment.

In recent years, economists have begun to be interested in how best to manage invasive pests. The literature generated by this interest focuses on two main policy questions. The first question considers optimal trade policy between importing and exporting countries for the prevention of new species introductions. The central tradeoff is between the damage foregone that would otherwise have been caused by an invader and the welfare lost by implementing two policy tools: a tariff added to reduce trade flows and the inspection of goods at ports of entry (e.g., McAusland and Costello 2003, Costello and McAusland 2004, Olson and Roy 2005). The second set of questions considers optimal eradication or suppression policies to control established invasive species. Olson and Roy (2002, 2008) set up and solve a stochastic dynamic optimization problem and show the conditions under which an eradication strategy becomes dominated by a suppression strategy. The central tradeoff here is between costs of control and benefits in terms of foregone damage. Several authors have examined these questions in a spatially explicit setting, including Sharov and Liebhold (1998a, 1998b) who formulate a dynamic optimization approach to solving for an optimal barrier zone.

Recently Mehta *et al.* (2007) incorporated the surveillance stage into the model of the invasive species management. They point out the importance of timing: eradication or suppression of invasive species populations can be conducted only after populations are found through surveillance activities. This implies that damage caused by invasive species continues to occur during the surveillance phase. Higher intensities of surveillance enable earlier population control and less environmental damage but cost more. This is the central tradeoff involved in determining the optimal intensity of surveillance. Focusing on this tradeoff, Homans and Horie (2008) modeled optimal surveillance of sub-populations of invasive species establishing ahead of an advancing front to determine the optimal effort to be devoted to find and treat these sub-populations.

While Mehta *et al.* (2007) and Homans and Horie (2008) focused on the timing issue raised by the order of management activities, this study focuses on location: the eradication or suppression of the species is possible only on the sites where surveillance is conducted. This implies a set of important tradeoffs that are considered when sites are selected for surveillance and treatment. When more sites are selected for surveillance, more sites are eligible for treatment; however, when a greater proportion of the budget is spent on surveillance, fewer resources are available for suppression and containment. To explore this, we build a two stage mixed integer programming model in which the objective is to minimize the number of newly infected trees. In the first stage, the manager chooses sites to be surveyed from all the sites in the management area. In the second stage, the manager determines the number of infested hosts to be removed within the sites surveyed in the first stage. This model is adapted from Snyder *et al.* (2004) who develop a similar model for the purpose of maximizing the expected number of species represented in sites selected for preservation.

In Section 2, we formulate our mixed integer programming model. In Section 3, we characterize the solution of the problem for a simple two site case. This case provides intuition for the more complex model in our application. In Section 4, we apply our model to the case of oak wilt management in Anoka County Minnesota and perform sensitivity analysis. Section 5 concludes with a discussion of the model and its implications.

2. Model Development

We develop a model of a single forest management area composed of a number of distinct sites. The manager's goal is to control the population of invasive species in his management area, and the overarching objective is to minimize the number of newly infected trees in a given year. The choice variables are (1) yes-no variables for each site indicating whether surveillance is undertaken in the inspection stage, and (2) the proportions of infected tree populations removed in each site in the treatment stage. We have two constraints. First, the budget constraint ensures that the total costs of surveillance and treatment do not exceed the budget level. Second, we ensure that treatment cannot occur in a given site unless the site has been inspected: the number of trees removed in each site is bounded above by the number of trees that have been identified as infected. We introduce this constraint because, for pathogens, the detection process of pathogen management needs to exactly identify an infected tree in each location. Treatment for pathogens is not broadcast (such as aerial spraying), but instead is applied to particular trees. Forest managers must know which trees are infected before removing them.

A Deterministic Management Model

The management area consists of J sites with a known number of possible host trees, N_j, on each site, $j = 1, \cdots, J$. A proportion, α_j, of these host trees are infected by an invasive species. Assuming first that this proportion is known, the number of infected trees (I_j) and healthy (H_j) trees at the beginning of the period can be written:

$$I_j \equiv \alpha_j N_j$$

$$H_j \equiv (1-\alpha_j) N_j$$

The manager has two sets of choice variables. The first is a binary variable (X_j) indicating whether a site is inspected ($X_j = 1$) or not ($X_j = 0$). The second is the number of infected trees removed, R_j, in each site. Infection occurs after tree removal. The number of newly infected trees, Q_j, in site j is a function of how many infected trees remain after the manager removes R_j trees from the site:

$$Q_j = \min[H_j, g_j \cdot (I_j - R_j)]. \tag{1}$$

This equation states that the number of infected trees grows exponentially (with growth parameter g_j), but cannot exceed the number of healthy trees. Growth rates for pathogens may be site-specific because growth may depend on characteristics such as tree density or soil type that vary over the landscape. Figure 1 illustrates this relationship. New infections, Q_j, are a function of the number of infected trees remaining after managers remove R_j trees from the original population of infected trees I_j so that the horizontal axis is the population of infected trees left after removal: $I_j - R_j$. The maximum amount of removal occurs at the origin where all infected trees are removed, and no new infections occur. The number of newly infected trees increases linearly as the number of trees removed is reduced (and $I_j - R_j$ increases) until a plateau is reached where the number of infected trees remaining after removal is high enough to infect all the remaining healthy trees. Further increases in infective trees (corresponding to further reductions in tree removal) can cause no additional damage because all healthy trees would already be infected. We define M_j as the number of trees removed at the start of this plateau. It represents the minimum number of trees that must be removed to preserve at least one healthy tree. We solve for the location of the start of the plateau by setting $H_j = g_j \cdot (I_j - M_j)$ and solving for M_j to get:

$$M_j \equiv I_j - \frac{H_j}{g_j} \quad . \tag{2}$$

As is shown in Figure 1, and reading from the right side of the figure, the number of newly infected trees Q_j remains H_j for $R_j \le M_j$ and it is linearly decreasing in the number of infected trees removed for $R_j > M_j$. Figure 1 also shows the possibility that no plateau exists. There will be no plateau when $I_j - \frac{H_j}{g_j} < 0$, when the growth rate is lower and there are abundant numbers of healthy trees relative to the number of infected trees.

The manager's objective is to minimize the number of newly infected trees:

$$\min \sum_{j=1}^{J} Q_j \tag{3}$$

subject to the constraint that tree removal can only occur in sites that have been inspected by the manager:

$$0 \le R_j \le I_j X_j , \tag{4}$$

and the budget constraint:

$$\sum_{j=1}^{J} d_j N_j X_j + \sum_{j=1}^{J} k_j R_j \leq B \tag{5}$$

where c_j is the per-tree cost of inspection, k_j is the per-tree cost of removal, and B is the size of the budget. This budget constraint reflects the notion that, once a site is selected for inspection, all trees must be examined and evaluated for the presence of the disease. The assumption of comprehensive inspection creates a fixed cost of site inspection that is an increasing function of the total number of trees on the site.

The solution procedure for this problem involves dividing the problem into two steps and solving the problem using backwards recursion. The manager's first step is to decide which sites to visit to identify the location of infested trees, and the second is to determine how many infected trees removed from the sites selected in the first step. In order to solve the problem, we first determine the optimal number of trees to be removed given a set of sites selected for surveillance (the second step in the two-step problem) and then solve for the optimal set of sites to survey (the first step).

Let $\overline{\Omega}$ be the set of all 2^J possible combinations of sites (i.e., the power set of a set of sites), and Ω be an element, which is a set containing sites selected for surveillance:

$$\Omega \in \overline{\Omega}.$$

For each possible set of sites selected for surveillance $\Omega \in \overline{\Omega}$, the forest manager chooses tree removal R_j, $j = 1, \cdots, J$, to solve the following problem:

$$\min \sum_{j \in \Omega} Q_j + \sum_{j \notin \Omega} Q_j \tag{6}$$

$$\text{subject to} \quad 0 \leq R_j \leq I_j \ \text{ for } \ j \in \Omega \tag{7}$$

$$R_j = 0 \text{ for } j \notin \Omega \tag{8}$$

$$Q_j = \min[H_j, g_j \cdot (I_j - R_j)] \text{ for } j = 1, \cdots, J \tag{9}$$

$$\sum_{j \in \Omega} k_j R_j \leq B - \sum_{j \in \Omega} d_j N_j \tag{10}$$

Let $R_j^*(\Omega)$, $j = 1, \cdots, J$ be the solution to this problem. Plugging this optimal number of trees removed into the objective function, we can obtain the number of newly infected trees resulting from this solution. Formally, we define the following function $\phi(\bullet)$ which depends on the set of sites selected surveillance Ω, $\phi : \overline{\Omega} \rightarrow \Re_+$ such that

$$\phi(\Omega) = \sum_{j \in \Omega} \min[H_j, g_j (I_j - R_j^*(\Omega))] + \sum_{j \notin \Omega} \min[H_j, g_j I_j] \quad \text{for any } \Omega \in \overline{\Omega}. \tag{11}$$

This function defines, given a set of sites surveyed, the minimum number of newly infected trees. This function can then be used to find the optimal set of sites to be surveyed. Continuing our backwards solution procedure, we solve the following problem by choosing the set of sites to be surveyed, $\Omega \in \overline{\Omega}$. This problem corresponds to choosing the yes-no variable X_j, for each site $j = 1, \cdots, J$ because Ω contains the sites with $X_j = 1$. The problem is to choose Ω to minimize the number of newly infected trees in the entire landscape, subject to the budget constraint:

$$\min \phi(\Omega) \tag{12}$$

$$\text{subject to } \Omega \in \overline{\Omega} \tag{13}$$

$$\sum_{j \in \Omega} c_j N_j \leq B - \sum_{j \in \Omega} k_j R_j^*(\Omega) \tag{14}$$

3. Characterizing the solution to a two site problem

This model is straightforward to apply to a multiple site landscape using any standard optimization software. In order to understand the interactions among the variables of the problem, however, it is helpful to consider a simplified problem involving only two possible locations. For the two site case, the set of all possible combinations of sites $\overline{\Omega}$ is given as

$$\overline{\Omega} = \{ Ø, \{1\}, \{2\}, \{1,2\} \},$$

where Ø is an empty set. In the following discussion, for any combination of sites $\Omega \in \overline{\Omega}$, we call Ω "affordable" if and only if inspection of all the trees on all sites in the set Ω does not exceed the original budget level, B:

$$\sum_{j \in \Omega} d_j N_j \le B .$$

Now, we characterize solutions for the tree removal stage, given a set of inspected sites. For each possible combination of inspected sites, Ω, the manager solves the problem defined above in (6) through (10).

First we consider the case when none of sites are selected for inspection in the surveillance stage: $\Omega =$ Ø. In this case, by the constraint given by Equation (8), cutting no infected trees on both sites is optimal:

$$R_j^*(\Omega) = 0 \text{ for } j = 1, 2.$$

Second, we consider cases where only one site is selected for inspection. Sets {1} and {2} are included in this category. Since only one site is selected for surveillance, it is optimal to cut as many infected trees on the site as possible within the budget left for infected tree removal, and not to cut any infected trees on sites not surveyed. Thus the solution is given as

$$R_a^*(\Omega) = I_a \text{ for } a \in \Omega \text{ and } R_b^*(\Omega) = 0 \text{ for } b \notin \Omega \text{ if } d_a N_a + k_a I_a \le B \text{ , or} \quad (15)$$

$$R_a^*(\Omega) = \frac{B - d_a N_a}{k_a} \text{ for } a \in \Omega \text{ and } R_b^*(\Omega) = 0 \text{ for } b \notin \Omega \text{ if } d_a N_a + k_a I_a > B . \quad (16)$$

Here, and in subsequent discussions, the higher priority site is labeled site "*a*" and the lower priority site is labeled site "*b*." This notation indicates priority and is distinct from the numerical notation that identifies particular sites (1,2).

In this case, since only one site is surveyed and infected tree removal is possible only on the site, the surveyed site becomes automatically the site with the first priority (i.e., assigned the notation *a*) and the site not surveyed becomes the site with second priority (i.e., assigned the notation *b*).

Third, it is possible that both sites are surveyed. Here, Ω is the set $\{1,2\}$. If the cost of cutting all the infected trees on all the sites in the set Ω does not exceed the budget left for infected tree removal (so that $\sum_{i\in\Omega} k_i I_i \le B - \sum_{i\in\Omega} d_i N_i$), then it is optimal to cut all the infected trees in both of the sites in the set Ω. That is,

$$R_j^*(\Omega) = I_j \text{ for any } j \in \Omega. \tag{17}$$

If the budget does not allow all trees in inspected sites to be removed, the manager must decide how to allocate the limited budget between the two sites. The higher priority sites are sites with the higher number of trees saved per dollar spent on tree removal. In the simplest case with many healthy trees, where the first tree removed is effective in reducing new infections (so that no plateau exists and $M_j = 0$), this ratio is given by g_j / k_j. A way to see that this is to note that $g_j R_j$ is equal to the number of tree saved, and $k_j R_j$ is equal to the cost of trees removed so that the quotient, g_j / k_j, is the cost per tree saved. However, when $M_j > 0$, it is possible to incur costs of removal without any resulting reduction in the number of new infections. This will occur when the remaining number of infected trees is sufficient to infect all remaining healthy trees on the site. In this case, the number of healthy trees saved per unit cost of removal is calculated as:

$$\begin{cases} 0 & \text{for } R_j \le M_j \\ \dfrac{g_j (R_j - M_j)}{k_j R_j} & \text{for } R_j > M_j. \end{cases}$$

The total cost of tree removal is k_jR_j, but the tree removal only becomes effective once M_j trees are removed so that the number of trees saved is $g_j(R_j - M_j)$. Therefore, the ratio that determines the highest priority sites depends on the number of infected trees, the number of healthy trees, and the number of trees removed.

Using the principle of choosing the site with the higher number of trees saved per dollar spent on tree removal, we can consider four types of solutions to the problem.

$$R_a^*(\Omega) = I_a \text{ and } R_b^*(\Omega) = \frac{B - \sum_{j\in\Omega} d_jN_j - k_aI_a}{k_b} \text{ for } a \text{ and } b \in \Omega$$

In other words, in one site (*a*), all infected trees will be removed. The rest of the budget will be spent on tree removal in the other site (*b*). One way in which this type of solution will occur is when the budget allows for complete removal on either one of the two sites, but not both. The higher priority site (site *a*) is the one in which complete tree removal will save a higher number of trees. Specifically, this case occurs when:

$$\sum_{j\in\Omega} k_jI_j > B - \sum_{j\in\Omega} d_jN_j \,,$$

$$k_aI_a \le B - \sum_{j\in\Omega} d_jN_j \,,$$

$$k_bI_b \le B - \sum_{j\in\Omega} d_jN_j \text{ , and}$$

$$\frac{g_a(I_a - M_a)}{k_aI_a} \ge \frac{g_b(I_b - M_b)}{k_bI_b} \,.$$

Another way in which this solution will occur is when the budget allows for complete removal of infected trees in one site (*a*) but not the other (*b*). In this case, the relevant comparison is between the number of trees saved when the entire budget is spent on one site versus the other. Complete tree removal will take place in site *a* if the number of trees saved when all infected trees are removed from site *a* exceeds the number of trees saved when the entire budget is spent on incomplete removal of trees from the alternative site (site *b*). This case occurs when these conditions are met:

$$\sum_{j\in\Omega} k_j I_j > B - \sum_{j\in\Omega} d_j N_j \ ,$$

$$k_a I_a \leq B - \sum_{j\in\Omega} d_j N_j \ ,$$

$$k_b I_b > B - \sum_{j\in\Omega} d_j N_j \text{ , and}$$

$$\frac{g_a(I_a - M_a)}{k_a I_a} \geq \frac{g_b\left\{(B - \sum_{j\in\Omega} c_j N_j)/k_b - M_b\right\}}{B - \sum_{j\in\Omega} c_j N_j} .$$

It may be possible for incomplete removal in a site to be optimal, even when complete removal in an alternative site is within the budget. In this case, the budget is exhausted in a site (*a*) where not all trees are removed, but this incomplete removal saves a greater number of trees than when the budget is allocated to an alternative site. This other solution is

$$R_a^*(\Omega) = \frac{B - \sum_{j\in\Omega} d_j N_j}{k_a} \text{ and } R_b^*(\Omega) = 0 \text{ for } a \text{ and } b \in \Omega$$

such that $k_a I_a > B - \sum_{j\in\Omega} d_j N_j$,

$$k_b I_b \leq B - \sum_{j\in\Omega} d_j N_j \text{ , and}$$

$$\frac{g_a\left\{(B-\sum_{j\in\Omega}d_jN_j)/k_a-M_a\right\}}{B-\sum_{j\in\Omega}d_jN_j}\geq\frac{g_b(I_b-M_b)}{k_bI_b}.$$

A final possibility occurs when the budget allows only incomplete removal in both sites. The higher priority site is again determined as the site where the most trees are saved given the budget available. Mathematically, this possibility happens when

$$k_aI_a > B-\sum_{j\in\Omega}d_jN_j\ ,$$

$$k_bI_b > B-\sum_{j\in\Omega}d_jN_j\ , \text{ and}$$

$$\frac{g_a\left\{(B-\sum_{j\in\Omega}d_jN_j)/k_a-M_a\right\}}{B-\sum_{j\in\Omega}d_jN_j}\geq\frac{g_b\left\{(B-\sum_{j\in\Omega}d_jN_j)/k_b-M_b\right\}}{B-\sum_{j\in\Omega}d_jN_j}.$$

To summarize, these solutions imply that, in the infected tree removal stage, budgets left over after surveillance takes place are optimally allocated to sites where more cost efficient suppression of newly infected trees can take place among the ones where surveillance has been conducted. That is, sites with a positive number of infected trees optimally removed are the ones where more trees can be saved from infection with less cost: these sites are characterized by higher pathogen spread rates g_i , more healthy trees , H_i (so that a plateau, if it exists, is small), and lower per-tree cost of removal, k_j. Note that the combination of a higher spread rate and fewer healthy trees results in a larger plateau.

Now we move to the site selection problem for surveillance. We solve the problem defined by (12), (13), and (14). Four types of solutions the surveillance problem can be considered: (i) no sites, (ii) one site, (iii) both sites selected for surveillance.

(i) *No sites are selected.* ($\Omega^* = \emptyset$): The necessary condition for this solution being optimal is

$$d_j N_j + k_j M_j > B \text{ for any } j \in \Omega \text{ and for any } \Omega \in \overline{\Omega}.$$

This condition will hold if the budget is so limited that it does not allow inspection of the least expensive site (i.e., $d_j N_j > B$). This condition could also be met even if inspection is affordable, if the budget allowed for tree removal is not enough to reduce the number of newly infected trees.

(ii) *Selecting only site a for surveillance is optimal* (i.e., $\Omega^* = \{a\}$): In order to find out whether selecting one site is optimal, we compare the number of infected trees removed in this one site to all other possibilities. Necessary conditions for the optimality of surveying only site *a* are the following:

(ii-1) $\{b\}$ is not affordable or $\phi(\{a\}) \le \phi(\{b\})$ and

(ii-2) $\{a,b\}$ is not affordable or $\phi(\{a\}) \le \phi(\{a,b\})$.

Condition (ii-1) indicates that preference will be given to a site that (1) is affordable to survey when the alternative site is not affordable or (2) results in fewer newly infected trees than the alternative. Condition (ii-2) compares surveying a single site to surveying both sites. Surveying a single site will be optimal if (1) it is not possible to survey both sites due to the budget constraint or (2) surveying a single site will result in fewer newly infected trees than surveying both sites.

Why might it be optimal to survey a single site when it is within the budget to survey both sites? We relegate a detailed accounting of the budget conditions to the Appendix, but the essential conclusion is that conditions (ii-1) and (ii-2) above hold when inspection and tree removal on only site *a* results in saving more healthy trees than if these activities are carried out either only on site *b* or on both sites *a* and *b*.

(iii) *Selecting two sites for surveillance is optimal* $\Omega^* = \{1,2\}$: To have this solution be optimal, the budget level has to satisfy $d_a N_a + d_b N_b + k_a I_a \leq B$. In addition, this strategy has to result in more healthy trees saved than with alternative strategies:

(iii-1) $\phi(\{1,2\}) \leq \phi(\{1\})$, and

(iii-2) $\phi(\{1,2\}) \leq \phi(\{2\})$.

4. Application

Our application is to the case of oak wilt in Anoka County, Minnesota. Oak wilt is one of the most notorious oak tree-killing fungal pathogens spreading in the eastern and central part of the United States. Anoka County has been severely affected by oak wilt and there are active programs, funded in partnership with the USDA Forest Service and the Minnesota ReLeaf fund, designed to limit further damage.

Data

We divide a part of Anoka County into 92 hexagonal grid cells sized 1 square kilometer. We have assembled data from various sources to characterize each grid cell by the number of oaks, the number of infected oaks, and the soil type (see Figure 2).

Total population of trees on site j (N_j): We calculate the total population of host trees for each grid cell by using the data obtained from the Minnesota Land Cover Classification System (MLCCS) (Minnesota Department of Natural Resources Central Region 2004). The MLCCS was created by the Minnesota Department of Natural Resource (DNR) and defines 253 land classifications for all of Anoka County. Using these land classifications and estimates of oak tree density for each land classification, we calculate the oak tree populations for each grid cell.

Population of infected trees on site j (I_j): A GIS data layer for areas covered by existing oak wilt infection pockets has been provided by the Minnesota DNR. We use this to determine the number of infected trees per grid cell.

Spread rate (g_j): Root grafting between healthy and infected trees and the sap beetle insect vector are two main factors causing transmission of infection among trees. In the case of oak wilt, spore mats formed on the surface of the dead infected oak trees attract sap beetles, and the beetles carry the fungus of oak wilt to healthy trees. However, since sap beetles likely exist uniformly in the range of our study area, we cannot estimate different new pocket formation rates for different grid cells. Adjacent trees, of which roots graft each other, share biological processes. Therefore a healthy tree grafting its root with an infected tree is more likely to be infected than one without root grafts (Epstein 1978). Moreover, roots are likely to spread father and form root grafts in sandy rather than heavy loamy soils. In this study, we differentiate infection spread rates of infection among grid cells by their soil types. The degree of sandiness ($0 \le \beta_j \le 1$) for each grid cell j is calculated by using the data obtained from provided by the Natural Resources Conservation Service, where larger β_j indicates sandier soil type of the grid cell. The soil type of every point in Anoka County is categorized into one of 24 categories defined by both upper and lower layers of the ground. We assign 1 to points where the soil types of either of upper or lower layers of their grounds are sandy so that we can identify the points of the space where root grafting more likely takes place. After dividing the Anoka County by grid cells, we assign the value of sandiness to each grid cell by aggregating the values of all the points within the grid cell. To do so, we took the average by weighting the values (0 or 1) of the points within the grid cells by the fraction of areas with the value 1. The spread rate of the infection g_j is given as

$$g_j = (1 + \lambda_\beta \beta_j) g$$

where $\lambda_\beta \ge 0$ is the coefficient reflecting the spatial difference of infection spread rate, and g is the common infection spread rate among grid cells. The parameter g is the benchmark value of the growth rate. When λ_β is set to be larger than zero, we assume that soil type affects the underground spread rate and thus creates a difference in infection spread rates among grid cells because soil types differ across the landscape. However, the literature gives us little guidance on which values of g and λ_β to select. For these parameters, we choose plausible values and conduct sensitivity analysis to assess the importance of the range of these values.

Surveillance cost (d_j): We calculate the surveillance cost from the wage rate of arborists employed by city and county governments. Arborists employed by governments tend to be ranked in GS6 or 7 in the General Schedule (GS) Locality Pay Table. Taking the average of means of salaries for GS6 and GS7, we calculate the salary for an arborist to be 17.03 dollars per hour. To diagnose whether a tree is diseased or not takes 10 minutes on average. Thus, inspection cost per tree results in 2.84 dollars (17.03 dollars × 1/6). We assume that the surveillance cost per tree is uniform over all the grid cells ($d_j = 2.84$ for $j = 1,\cdots,92$).

Tree removal cost (k_j): The per-tree cost of removal usually depends on both the location and the size of a tree. Larger trees cost more to be removed. On average, trees in Anoka County are 10.475 diameter breast height (dbh). We use this average value for all trees removed so that the per-tree cost of removal is assumed to be 360 dollars as a benchmark value. It is costlier to remove trees in developed areas because of the difficulty of navigating around buildings and cables above ground and utility lines below ground. The same size tree costs more to be removed in highly developed and crowded areas than in less developed and crowded areas[1] (Coulson and Witter 1984). The degree of development of the land for each grid cell is graded from 0 to 1 by using GIS data obtained from National Land Cover Data Base.

$$k_j = 360(1 + \lambda_\gamma \gamma_j)$$

[1] For example, Maryland Department of Agriculture (MDA), Plant Protection and Weed Management Section (2008) gives tree-cutting companies (bidders) instructions about an procurement auction to quarantine Ash borer-infested areas. In the instructions, MDA gives examples of prices paid to cut trees on rural (undeveloped) and urban (developed) areas; the price to cut any size of trees on urban area is at least twice as high as those on rural areas. This is consistent with what Coulson and Witter (1984) report, although we know that MDA declares that the examples are mentioned for bidding purposes only and are not guaranteed or implied contract amounts or payments for contracted work.

where γ_j is the degree of development of grid cell j, and $\lambda_\gamma \geq 0$ is the coefficient indicating how seriously the scale of development affects the per-tree cost of removal. It is costlier to remove trees in more highly developed areas due to the difficulty of avoiding obstacles such as buildings and cables. Based on the Maryland Department of Agriculture (2008) bidding instructions discussed in Footnote 1, we set the value of λ_γ to be 1 so that the per-tree cost removal on the most ($\gamma_j = 1$) developed site j is as twice as costly as the one on the least ($\gamma_{j'} = 0$) developed site j'.

Results

The problem specified in Equations (3), (4), and (5) is solved by using the integrated solution package GAMS (GAMS Development Corporation 1990), which is designed for large and complex linear and mixed integer programming problems. We solve the model for 36 different budget levels from 200,000 to 7.4 million dollars. We report the level of budgets required to achieve given percentages of healthy trees saved from infection, which is the cost curve, in Figure 3. The vertical distance between the two cost curves in Figure 4 measures the additional cost required to save a given number of healthy trees when the parameter λ_β is changed from 1 to 3. The parameter λ_β is a measure of the sensitivity of the radial growth rate to soil type. When $\lambda_\beta = 0$, the radial growth rate is simply equal to *g*. An increase in λ_β increases the radial growth rate in cells where $\beta_j > 0$ and also increases the heterogeneity of growth rates among cells. For example, the increase in sensitivity to soil type from $\lambda_\beta = 1$ to $\lambda_\beta = 3$ leads to a cost reduction of \$200,000 to save 70% of the healthy trees in our study area. This result is attributable to the lower amount spent on surveillance when more trees are infected. The slopes of these cost curves are the marginal cost, showing the cost of each additional increment in the percentage of healthy trees saved from infection. More sensitivity to soil type in the infection spread rate among grid cells leads to smaller marginal costs when a lower percentage of healthy trees are saved from infection, and bigger marginal costs when relatively higher percentages of healthy trees are targeted to be saved from infection.

The optimal fraction of the budget spent on inspection (versus tree removal) varies with the budget level. This is shown in Figure 5. Solid and dotted lines correspond to the expenses for the inspection when $\lambda_\beta = 1$ and $\lambda_\beta = 3$ respectively. This amount is sensitive to the parameter λ_β. When the budget is less than $4 million, a higher sensitivity to soil type (λ_β) reduces the portion of the budget spent on surveillance. When the budget is greater than $4 million, a higher sensitivity to soil type increases the portion of the budget spent on surveillance. The intuition for this is that a higher degree of spatial heterogeneity in spread (corresponding with greater sensitivity to soil type) results in less surveillance so that the manager can save a higher fraction of the budget for tree removal when budgets are limited. On the other hand, under the same situation of the pathogen spread rates, when budgets are more generous (greater than $4 milion), it is optimal to aggressively inspect trees.

For clearer intuition, let us relate this result with the necessary conditions derived above for the two stages of the two site problem. Remember that, given the set of sites surveyed, the higher priority sites for tree removal are those with smaller plateaus in the spread function (M_j), lower per-tree-removal costs (k_j) and higher spread rates (g_j). Since, in our application to oak wilt management in Anoka County, the population of infected trees is so low that no grid cells have a plateau in its spread function; the spread function is linear in the number of infested trees left over after tree removal ($I_j - R_j$). Thus, the marginal rate of healthy trees saved by tree removal is the same as the average rate: g_j / k_j. Given the sites selected for surveillance, an increase in λ_β from 0 to 1 increases the priority of cells with sandier soils because the growth rates in these cells become higher. However, increases in λ_β from 1 to 3 imply no changes in the priority ordering tree removal on the surveyed sites. Though the priority ordering does not change, the number of trees identified as infected does change when spread rates are higher in some cells. When λ_β increases, more infected trees are identified with the same surveillance budget. In the sites with high numbers of infected trees and higher spread rates, more trees are saved. However, the manager then must scale back removal in the lowest priority site because more trees are removed in higher priority sites. The consequences of this higher rate of tree removal may include dropping the lower priority sites from surveillance altogether, thereby reducing the portion of the budget spent on surveillance.

Grid cells with sandy soils (corresponding to higher value of β_j's), which are sensitive to the increase in λ_β, attain higher marginal number of saved healthy trees in the removal stage. This leads the manager to select such sites for the surveillance with priority in the surveillance stage when λ_β increases.

5. Discussion

The most effective strategy for limiting the spread of invasive forest pathogens such as oak wilt is to find and remove affected trees. The detection step is an important one, because trees must be specifically identified as being diseased before being removed; broadcast aerial spraying, for example, is not an option for control of fungi. However, there has generally been little attention paid to the problem of determining how much effort should be devoted to detection of invaders. We use a mixed integer programming approach, inspired by the site selection literature, to choose locations in a grid on which to focus detection and control efforts in a budget-constrained setting. Locations vary by the number of susceptible trees, the number of infected trees, the infection rate, and the cost of tree removal. We characterize the solutions for the infected tree removal stage, and the ones for the surveillance stage. Solutions in the infected tree removal stage imply that, in the infected tree removal stage, budgets left over after surveillance takes place are optimally allocated to sites where more cost efficient suppression of newly infected trees can take place among the ones where surveillance is conducted. That is, sites with positive numbers of infected trees optimally removed are the ones where more trees can be saved from infection with less cost: these sites are characterized by higher pathogen spread rates, more healthy trees, and lower per-tree cost of removal. Necessary conditions for the solutions in the surveillance stage imply that sites on which more healthy trees can be saved from spending a unit of inspection cost tend to be chosen for the inspection. Therefore sites with higher inspection costs due to a high number of trees have to have higher infection spread rates or lower per-tree removal cost if those sites are to be selected for surveillance over sites with fewer trees.

We apply our model to the case of Anoka County, Minnesota, a county with a severe oak wilt problem. We use our model to determine which sites within Anoka County should be given highest priority for inspection and removal. Our model is adaptable to other regions, for which oak wilt is a potential problem. The primary contribution of our study is to offer a tool suggesting practical guidance to managers in charge of deciding how and where to spend limited public dollars when the goal is to reduce the number of trees newly infected by oak wilt. We construct a curve that reflects the cost of protecting healthy trees from infection. This curve provides the manager with information about the level of budgets required to achieve targeted percentages of healthy trees saved from infection. The marginal cost of saving an additional healthy tree from the pathogen increases as the targeted protection level is set higher. We examine the impact of the increase in spatial heterogeneity of the pathogen spread rate among grid cells on the total management costs and the allocation of the costs between surveillance and removal. When the growth rate is more spatially heterogeneous due to a higher sensitivity to soil type, inspecting fewer trees is optimal if the budget level is relatively low and inspecting more trees is optimal if the budget level is relatively high.

References

A. Ando, J. Camm, Camm, S. Polasky, A. Solow, Species Distributions, land values, and effcient conservation, Sci. 279 (1998) 2126-28.

R. L. Church, D. M. Stoms, F. W. Davis, Reserve selection as a maximal covering location problem, Biol. Cons. 76 (1996)105-112.

C. Costello, C. McAusland, Protectionism, Trade, and measures of damage from exotic species introductions, Amer. J. Agr. Econ. 85 (2003) 964-975.

R. N. Coulson, J. A. Witter, Forest Entomology: Ecology and Management, Wiley-Interscience 2nd Edition: (1984).

E. M. Hansen, Alien forest pathogens: Phytophthora species are changing world forests, Boreal Env. Res. 13 (2008) 33-41.

F. R. Homans, T. Horie, Optimal detection strategies for an established invasive pest, Department of Applied Economics, University of Minnesota, (2008) mimeo.

T. P. Holmes, J. E. Aukema, B. V. Holle, A. Liebhold, E. Sills, Economic impacts of invasive species in forests past, present, and future, The Year in Ecology and Conservation Biology, Ann the New York Ac. of Sci. 1162 (2009) 18-38.

J. A. Loo, Ecological impacts of non-indigenous invasive fungi as forest pathogens, Biol. Invasions 11 (2009) 81–96.

C. R. Margules, A. O. Nicholls, R. L. Pressey, Selecting networks of reserves to maximize biological diversity, Biol. Cons. 43 (1988) 63-76.

Maryland Department of Agriculture Plant Protection and Weed Management Section, 2007/2008 Landscape Ash Tree Removal for Emerald Ash Borer Eradication Bid Announcement and Instructions, (2007).
http://www.mda.state.md.us/plants-pests/eab/bid/arborist_bid_announcement.pdf

C. McAusland, C. Costello, Avoiding invasives: Trade-related policies for controlling unintentional exotic species introductions, J. Environ. Econ. Manage. 48 (2004) 954-977.

S. Mehta, R. G. Haight, F. R. Homans, S. Polasky, R. C. Venette, Optimal detection and control strategies for invasive species, Ecol. Econ. 61 (2007) 237-245.

Minnesota Department of Natural Resources Central Region, Minnesota land cover classification system user manual, version 5.4 (2004)
http://files.dnr.state.mn.us/assistance/nrplanning/community/mlccs/mlccs_manual_v5_4.pdf

L. J. Olson, S. Roy, The economics of controlling a stochastic biological invasion, Amer. J. Agr. Econ. 84 (2004) 1311-1316.

L. J. Olson, S. Roy, On prevention and control of an uncertain biological invasion", Rev. of Agr. Econ. 27 (2005) 491-97.

L. J. Olson, The economics of terrestrial invasive species: A review of the literature, Agri. and Res. Econ. Rev. 35 (2006) 178-194.

L. J. Olson, S. Roy, Controlling a biological invasion: A non-classical dynamic economic model", Econ. Theory 36 (2008) 453-69.

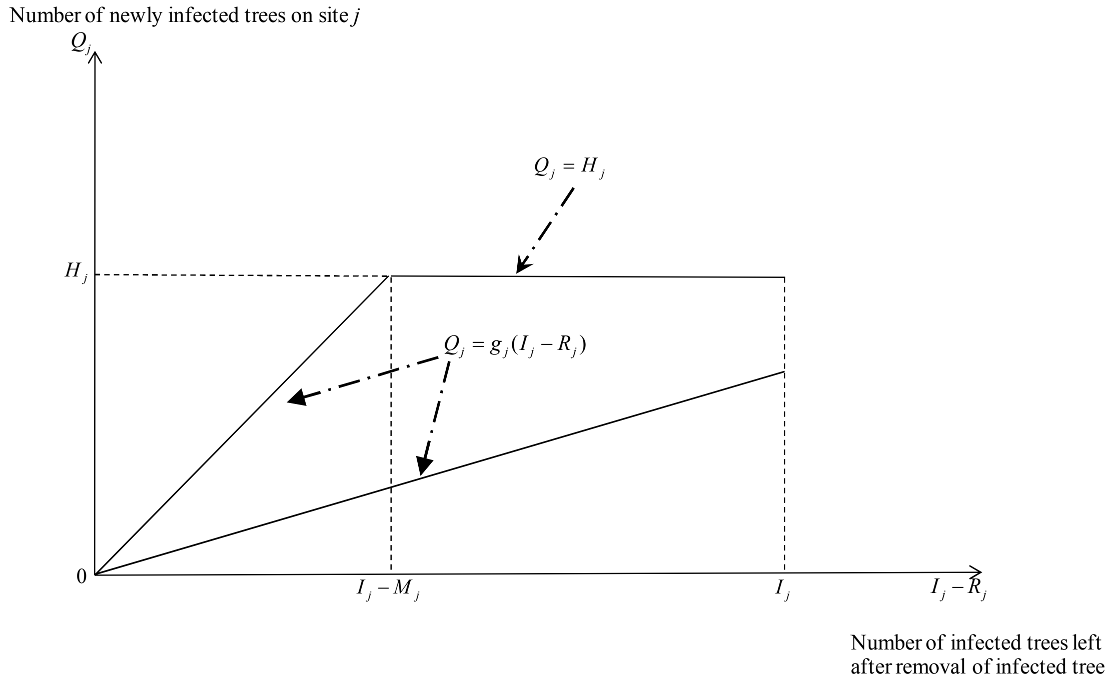
D. Pimentel, L. Lach, R. Zuniga, D. Morrison, Environmental and economic costs of nonindigenous species in the United States, BioSci. 50 (2000) 53-65.

S. Polasky, J. D. Camm, B. Garber-Yonts, Selecting biological reserves cost-effectively: An application to terrestrial vertebrate conservation in Oregon, Land Econ. 77 (2001) 68-81.

J. N. Stokland, Representativeness and efficiency of bird and insect conservation in Norwegian boreal forest reserves, Cons. Biol. 11 (1997) 101-111.

S. A. Snyder, R. G. Haight, C. S. ReVelle, A scenario optimization model for dynamic reserve site selection, Environ. Modeling Assess. 9 (2004) 179-187.

Figure 1.



Number of newly infected trees on site j
Q_j
$Q_j = H_j$
H_j
$Q_j = g_j(I_j - R_j)$
0
$I_j - M_j$
I_j
$I_j - R_j$
Number of infected trees left after removal of infected tree

Figure 2. Study area in Anoka County, Minnesota. Red polygons indicate oak wilt infections.

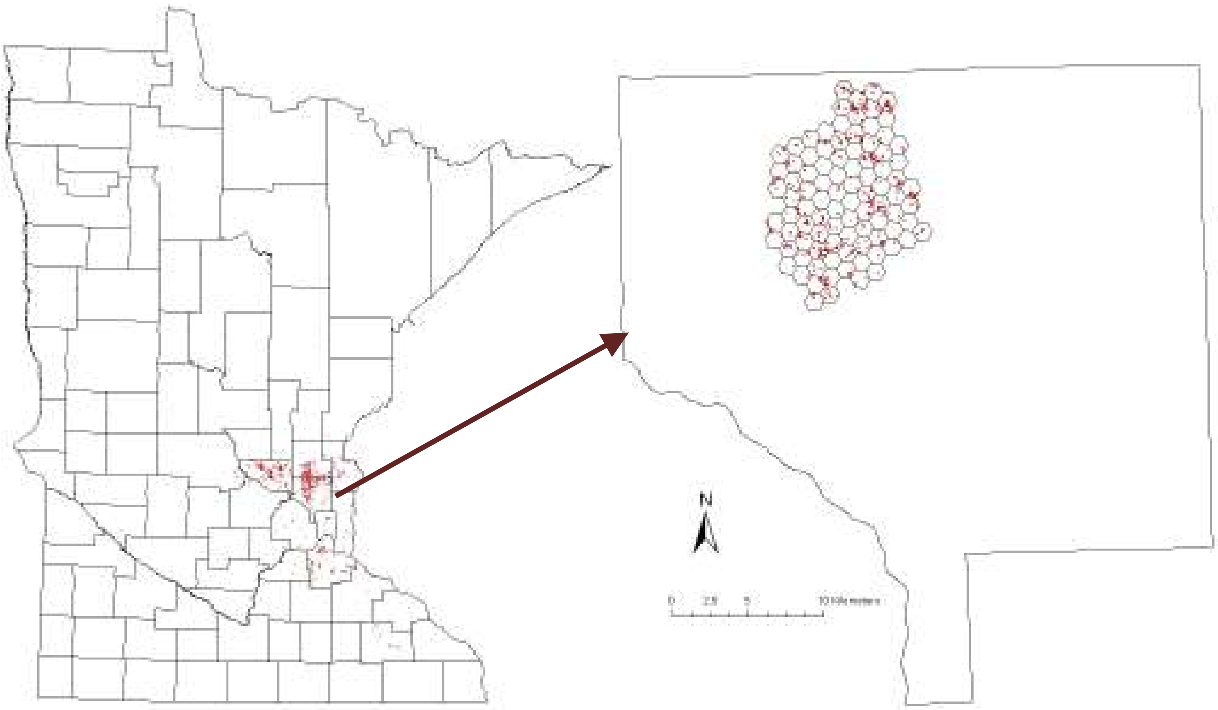


Figure 3. Cost curves for the targeted fraction of healthy trees saved

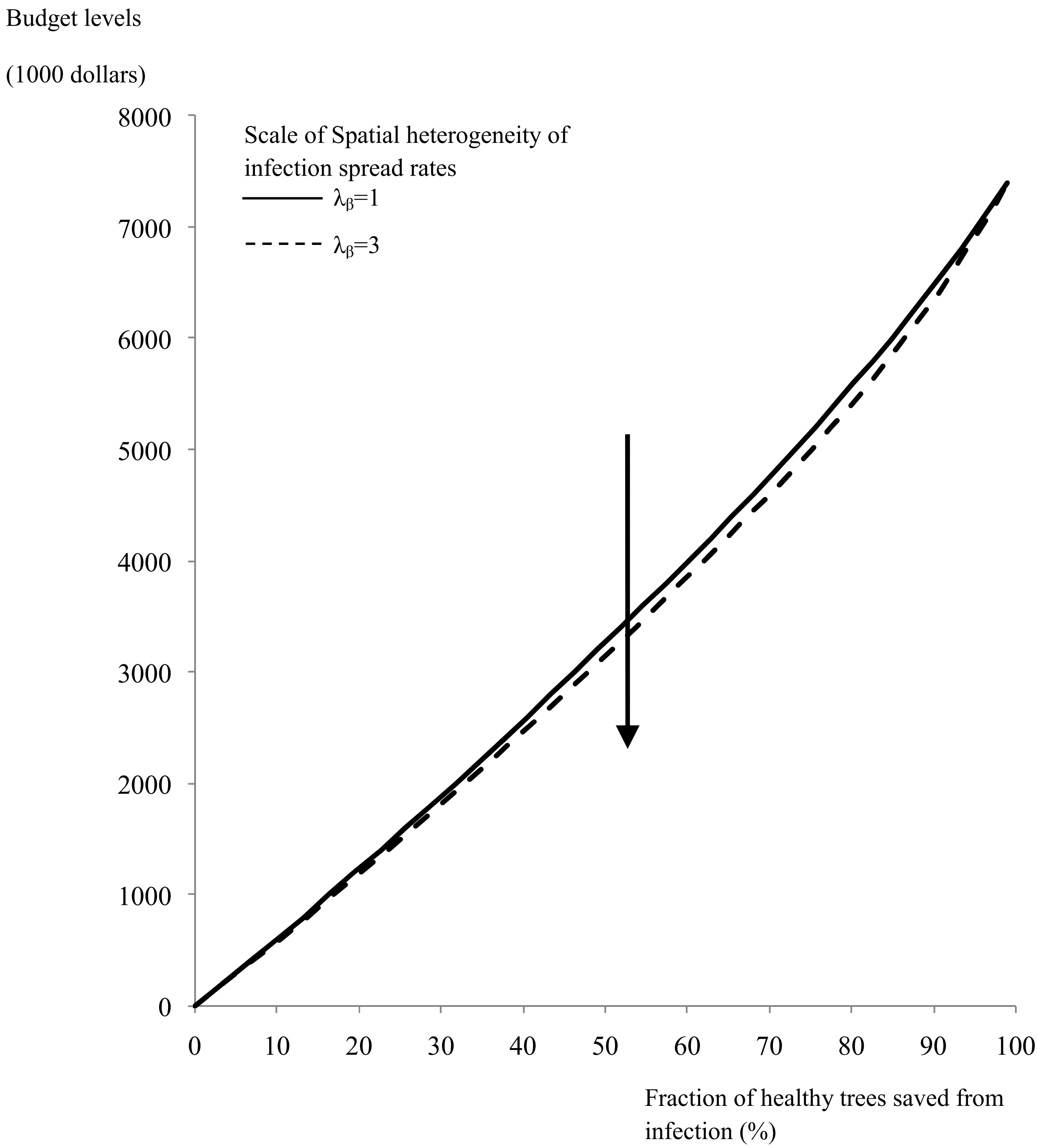
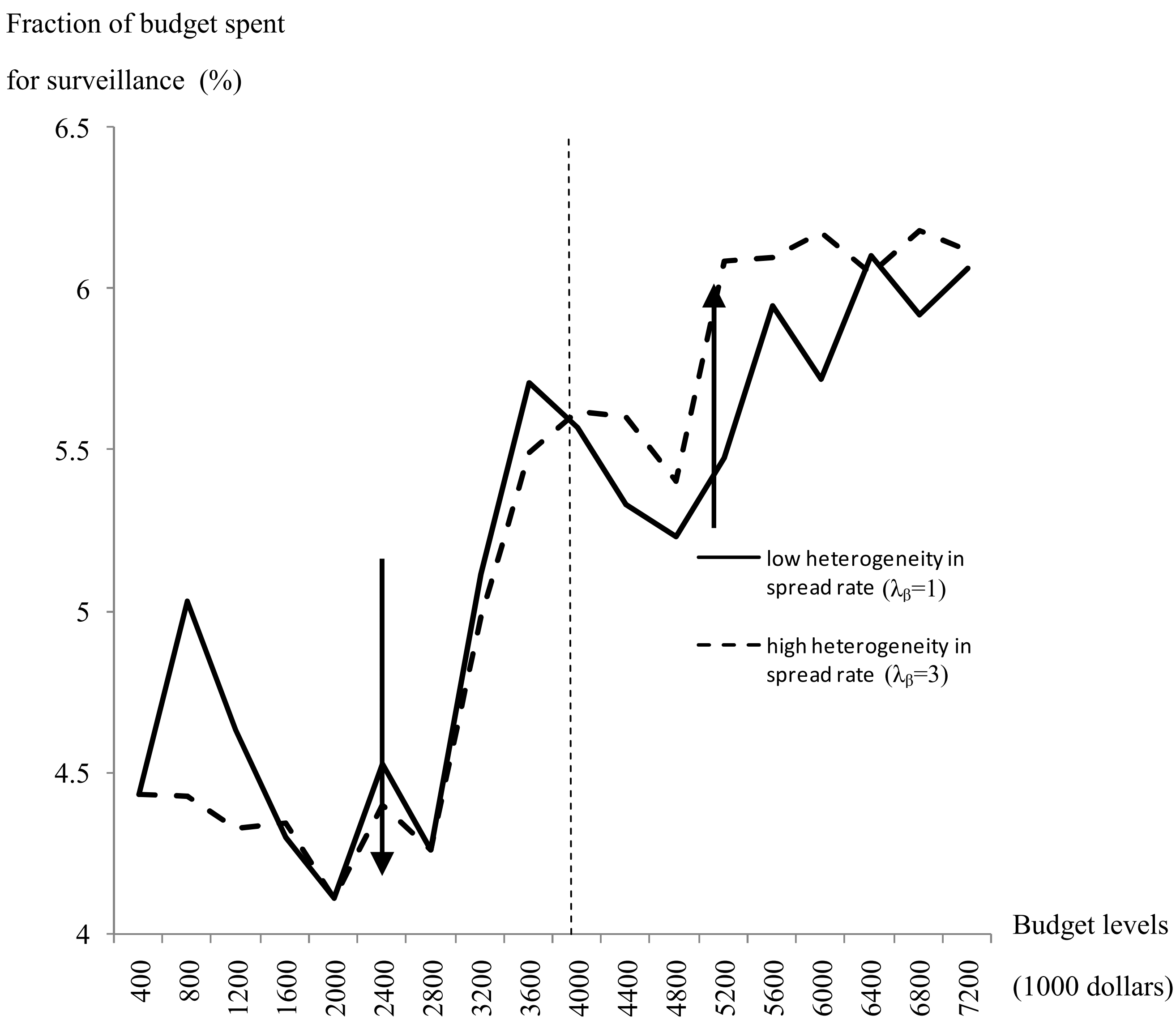


Figure 4.


Fraction of budget spent
for surveillance (%)
6.5
6
5.5
5
4.5
4
Budget levels
(1000 dollars)
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
4800
5200
5600
6000
6400
6800
7200
low heterogeneity in spread rate (λβ=1)
high heterogeneity in spread rate (λβ=3)

Appendix: Derivation of necessary conditions for the optimal solution for the surveillance stage

Selecting only site a for surveillance is optimal (i.e., $\Omega^* = \{a\}$):

First, when the budget level allows the inspection on both sites and complete removal of infected trees only on the site a and (i.e., $d_a N_a + d_b N_b + k_a I_a \le B$) then (ii-1) and (ii-2) are characterized as follows.

$$\text{(ii-1)} \Leftrightarrow g_a\left(I_a - M_a\right) \ge g_b\left(I_b - M_b\right)$$

$$\text{(ii-2)} \Leftrightarrow g_b\left(\frac{B - d_a N_a - d_b N_b - k_a I_a}{k_b} - M_b\right) \le 0$$

A site with more infected trees I_a and less plateau M_a (i.e., more healthy trees, $H_a = N_a - I_a$) and higher spread rate g_a is selected for the surveillance. The second inequality holds if the infection spread rate on the site b is zero ($g_b = 0$) or the amount of budget left for the tree removal on the site b is not enough to cut more infected trees than M_a, which is the minimum number of infected trees removed to save positive number of healthy trees on the site.

Second, we consider the level of budget, which cannot cover the costs for inspection on both sites and complete infected tree removal on the site a but can cover the costs for the inspection and complete infected tree removal on the site a and b (i.e., $d_a N_a + d_b N_b + k_a I_a > B$, $d_a N_a + k_a I_a \le B$, and $d_b N_b + k_b I_b \le B$). In this case, the necessary conditions are characterized by

$$\text{(ii-1)} \Leftrightarrow g_a\left(I_a - M_a\right) \ge g_b\left(I_b - M_b\right)$$

$$\text{(ii-2)} \Leftrightarrow g_a\left(I_a - M_a\right) \ge g_a\left(\frac{B - d_a N_a - d_b N_b}{k_a} - M_a\right).$$

The first inequality is the same as the first case, and the second inequality automatically holds.

Third possible alternative situation is when the manager is given the budget not enough to survey and cut all the infected trees on the site a but enough to survey and cut all the infected trees on the site b (i.e., $d_a N_a + k_a I_a > B$ and $d_b N_b + k_b I_b \le B$).

$$\text{(ii-1)} \Leftrightarrow g_a\left(\frac{B - d_a N_a}{k_a} - M_a\right) \ge g_b\left(I_b - M_b\right)$$

$$\text{(ii-2)} \Leftrightarrow g_a\left(\frac{B-d_aN_a}{k_a}-M_a\right) \geq g_a\left(\frac{B-d_aN_a-d_bN_b}{k_a}-M_a\right)$$

Again, (ii-2) holds automatically.

The fourth possible situation is that the manager has the budget much enough to survey both sites and remove all the infected trees on the site *a* ($d_aN_a+d_bN_b+k_aI_a \leq B$), but the budget is not enough to survey and remove all the infected trees on only site *b* ($d_bN_b+k_bI_b > B$). In this case, we have:

$$\text{(ii-1)} \Leftrightarrow g_a(I_a-M_a) \geq g_b\left(\frac{B-d_bN_b}{k_b}-M_b\right)$$

$$\text{(ii-2)} \Leftrightarrow g_b\left(\frac{B-d_aN_a-d_bN_b-k_aI_a}{k_b}-M_b\right) \leq 0$$

The fifth situation is where budget level is that the budget level is high enough to survey both sites ($d_aN_a+d_bN_b < B$) but it is not to cut down all infected trees on the site *a* ($d_aN_a+d_bN_b+k_aI_a > B$). Moreover, if the manager spend her budget only for the surveillance on the site *a* it is possible for her to remove all the trees on the site ($d_aN_a+k_aI_a \leq B$), but if she conducts surveillance only on the site *b* complete removal of infected trees on the site *b* ($d_bN_b+k_bI_b > B$). Under this situation, the conditions are characterized as follows.

$$\text{(ii-1)} \Leftrightarrow g_a(I_a-M_a) \geq g_b\left(\frac{B-d_bN_b}{k_b}-M_b\right)$$

$$\text{(ii-2)} \Leftrightarrow g_a(I_a-M_a) \geq g_a\left(\frac{B-d_aN_a-d_bN_b}{k_a}-M_a\right)$$

The last situation is that costs of removing all the infected trees on any site *a* or *b* exceed the budget (i.e., $d_aN_a+k_aI_a > B$ and $d_bN_b+k_bI_b > B$). In this case the condition is characterized by

$$\text{(ii-1)} \Leftrightarrow g_a\left(\frac{B-d_aN_a}{k_a}-M_a\right) \geq g_b\left(\frac{B-d_bN_b}{k_b}-M_b\right)$$

$$\text{(ii-2)} \Leftrightarrow g_a\left(\frac{B-d_aN_a}{k_a}-M_a\right) \geq g_a\left(\frac{B-d_aN_a-d_bN_b}{k_a}-M_a\right)$$

This inequality implies that, under this situation, the site *a* tends to be selected for the inspection if the combinations of relatively high infection, less plateau, and high spread rate of infection appear on the site or the combinations of low infection, more plateau, and low spread rate of infection on the site b appear. In this case, apart from the former case, the cost required for the inspection on the site *b*, $d_b N_b$, involves with this condition. Both high per-tree inspection cost d_b and large population N_b on the site *b* lead fewer budgets left for the tree removal on the site *b*. This also results in the less saved healthy trees from infection on the site.

Selecting two sites for surveillance is optimal $\Omega^* = \{1,2\}$:

To have this solution optimal, obviously the budget level has to satisfy $d_a N_a + d_b N_b + k_a I_a \le B$ where, as was referred in the tree removal stage above, the notation "*a*" indicates the site where the infected trees should be removed with the first priority among site 1 and 2, and "*b*" indicates the site with second priority. Necessary conditions are following.

(iii-1) $\phi(\{1,2\}) \le \phi(\{1\})$, and

(iii-2) $\phi(\{1,2\}) \le \phi(\{2\})$.

Adding to the condition such that surveying both sites and cutting all trees ($d_a N_a + d_b N_b + k_a I_a \le B$), if the budget level satisfies $d_b N_b + k_b I_b \le B$, the conditions (iii-1) and (iii-2) are characterized as:

$$\left.\begin{matrix}\text{(iii-1)}\\\text{(iii-2)}\end{matrix}\right\} \Leftrightarrow \begin{cases} g_b\left(\dfrac{B - d_a N_a - d_b N_b - k_a I_a}{k_b} - M_b\right) \ge 0 \\ g_a(I_a - M_a) + g_b\left(\dfrac{B - d_a N_a - d_b N_b - k_a I_a}{k_b} - M_b\right) \ge g_b(I_b - M_b) \end{cases}$$

If the budget level satisfies $d_b N_b + k_b I_b > B$, the conditions are characterized as follows.

$$\left.\begin{matrix}\text{(iii-1)}\\\text{(iii-2)}\end{matrix}\right\} \Leftrightarrow \begin{cases} g_b\left(\dfrac{B - d_a N_a - d_b N_b - k_a I_a}{k_b} - M_b\right) \ge 0 \\ g_a(I_a - M_a) + g_b\left(\dfrac{B - d_a N_a - d_b N_b - k_a I_a}{k_b} - M_b\right) \ge g_b\left(\dfrac{B - d_b N_b}{k_b} - M_b\right) \end{cases}$$

Social Benefits of Environmental Information from Geostationary Environmental Monitoring Satellite (GEMS):

Young Sook Eom*, Jong Ho Hong**

July 2010

***Young Sook Eom**

Department of Economics,

Chon Buk National University

664-14 1Ga Duck Jin Dong, Duck Jin Ku

Jeon Ju, Jeon Buk, 561-756, S. Korea

Ph: 82-63-270-3036

Cell phone: 82-10-3678-3060

Email: yeom@jbnu.ac.kr

****Jong Ho Hong**

Graduate School of Environmental Studies

Seoul National University

599 Gwanak-ro, Gwanak-gu

Seoul, 151-742, Korea

O) +82-2-880-9518

Fax) +82-2-871-8847

Email: hongjongho@snu.ac.kr

Social Benefits of Environmental Information from Geostationary Environmental Monitoring Satellite (GEMS)

I. Introduction

While Korean government has made steady progress toward achieving cleaner air quality by better managing and regulating domestic pollution sources, there are increasing threats from trans-boundary air pollutants such as Asian dust and trace metal, which are transported from neighboring countries such as China and other Asian countries. As an alternative to monitor regional and global causes in addition to improving domestic air quality monitoring and forecasting system, Korean government is planning to launch a multi-purpose geostationary satellite equipped with an environmental payload as well as meteorological and ocean color monitoring missions by 2017 (Chang, 2009; Kim, 2009).[1]

Coupled with in-situ ground level monitoring stations, the environmental payload named Geostationary Environmental Monitoring Satellite (GEMS) is expected to provide environmental information, which will support the mission of improving monitoring of SO_2, NO_2, O_3 and aerosol using UV/Visible spectrometer from geostationary orbit, and consequently enhance air quality forecasting (Kim, 2009).

Space development programs such as launching multi-purpose geostationary satellite entails a significant amount of public fund allocation. However, it is difficult to apply conventional benefit-cost analysis approach in measuring social benefits from GEMS, because the information from data products provided by GEMS is close to pure public goods, and R&D technology of space science has considerable spill-over effects across various aspects of the society. This paper is to measure ex ante social benefits of launching a multi-purpose satellite (i.e., GEMS) in the form of value of environmental information by using contingent valuation method (CVM).

Currently ground in-situ monitoring stations across the country generate information about air quality in the context of the comprehensive air quality index (CAI), a continuous index that converts forecasted daily air pollution levels into an easily understandable format with wording,

[1] Geostationary satellite is designed to operate in geostationary orbit, 35,790 km (22,240 statute miles) above the earth, thereby remaining stationary with respect to a point on the ground, the advanced spacecraft continuously view one-third of the earth, the Pacific-Asia area including Korea.

numbers and colors. And depending on the level of air pollution, Ministry of Environment and local agencies advise the public regarding health effects and preventive actions. Furthermore, various public media channels, including websites, TV and radio, announce “ozone alert” or “PM alert” when forecasted ambient ozone and/or PM levels exceed particular thresholds.

Satellite data, particularly GEMS imagery data, is expected to accomplish higher spatial and temporal resolutions in air quality applications, and thus have a significant role in improving air quality monitoring and forecasting (Kim, 2009). The better and more detailed the data with higher spatial and temporal resolutions, the more accurate the air quality models, and the better the timing and extent of warnings and mitigating measures (NASA, 2007). In addition, GEMS imagery data will dramatically improve the capabilities of tracking path of trans-boundary pollutants and some “exceptional” plumes, which are either natural or human induced. Furthermore, improved air quality monitoring and forecasting will help position the country as a leader in air quality issues on the international stage.[2]

The improved environmental information generated from geostationary data has potential impacts on the public health and properties to the extent that individuals respond to the information and adjust their activities to reduce their exposure to air pollution.[3] Especially, the air quality information including pollution alerts and/or warnings can encourage susceptible groups of individuals including children and elderly to adjust daily activities to avoid exposure to air pollutants. The air quality information will also motivate much of the public to adjust their work or school related activities, if possible, and to avoid rigorous outdoor activities. The positive economic impacts of air quality information on the public can be calculated as social benefits of strengthening the current system of air quality measurement, modeling and forecasting.

While eliciting economic impacts of improved information by utilizing GEMS data is of obvious interest, estimation of the economic value is not so obvious because most of those

[2] At the same time framework, NASA in USA and ESA (European Space Agency) in EU are also preceding a similar project to Korea’s GEMS program. However, GEMS of Korea will be the first geostationary environmental payload launched into orbit if the launching time schedule is met on time.

[3] In addition to the potential effects on public health, social benefits associated improved information from GEMS is the following: (1) the nation as a whole benefits form more informed policy decisions. (2) local governments will be better off by utilizing the information to better comply to ME standards, avoiding penalties (3) “polluters” will have more data to make the right decisions in cooperation with local governments (4) users of clean air will be able to better plan their infrastructure and better manage their operations (5) New Products and services will emerge to satisfy the need for clean air, outside, in the workplace, at home and for personal enjoyment (6) individuals and services affected by the health related impacts of air quality (NOAA, 2007).

effects are intangible and non-market services, which lead us to apply the contingent valuation method (CVM). To our knowledge, this is the first study of measuring “value of environmental information” about air quality changes, which is quite different from valuing more conventional contingent commodity such as change in air quality itself. Thus, a due care was taken in defining the contingent commodity being valued as well as applying appropriate methodology to estimate respondents’ willingness to pay. We tried to estimate alternative models where one utilizes full sample, while the other uses sample selection model to incorporate the potential effects of protest bids (Mitchell and Carson, 1989; Eom and Hong, 2009). The latter is to correct potential sample selection bias if there exist systematic differences between respondents who participate in the WTP question and those who protest.

We also have implemented in our CV survey an experimental design to test alternative payment vehicles. In addition to a mandatory charge in the form of an objective tax, which is commonly used in CVM studies of public goods, we adopted another voluntary and personalized charge—additional fee of text message service of cell phone bill. Whether the choice of a particular payment vehicle affects individuals’ willingness to pay has been raised by recent studies (Hackl et al., 2005; Wiser, 2007)

The paper is organized as follows. Section 2 provides a theoretical model to incorporate environmental information into consumer. Section 3, taking into account the unfamiliarity of the given contingent commodity in this study, gives a detailed description of CV survey design and data collection process. Section 4 presents empirical results of single-bounded dichotomous choice CV response. Section 5 concludes with a discussion of the implications of empirical findings and directions for further work.

II. Modeling Individuals’ Stated Preferences for Environmental Information

Suppose a representative individual’s preference depends on a *numeraire* composite good, Y, and the state of health, z, that are posed by air pollutants. The individual’s utility may be expressed as:

$$U = U(Y, z) \qquad (1)$$

However, the individual may not know with certainty what health state will be realized for the next few days given the condition of air pollution in the region. Especially some air pollutants (such as O_3, PM and Asian dusts) are suspected to be linked to variety of adverse health effects, including asthma, bronchitis and respiratory distress symptoms so on. Sensitive groups of population including children, the elderly, pregnant women, and those with pre-existing cardio-respiratory diseases are especially vulnerable to these adverse health effects.

For simplicity, it is assumed that the individual faces only two states of the world: the occurrence (*z*=1) or non-occurrence (*z*=0) of the adverse health symptoms associated due to exposure to air pollutants.[4] In addition, he is assumed to evaluate consumed goods differently depending on his health status, implying state dependent preferences (Cook and Graham, 1977). Furthermore the individual does not know the 'objective' probability of adverse health outcome but may form subjective probabilistic beliefs based on self-protection undertaken (*s*) and information about the health risk (*I*). That is, the individual's subjective risk perception is defined as

$$\pi = \pi(s, I) \qquad (2)$$

Self-protection actions that the individual can take (*s*) include avoiding outdoor activities or wearing masks, or installing air purifiers so on. Each individual may perceive a different degree of subjective health risk due to air pollution according to his or her demographic background, knowledge about the event at risk, and past experiences with similar situations. These factors will serve as a set of information, *I*, to the individual in the process of forming risk perceptions at a point in time. Part of available information, *I*, may be provided by the Ministry of Environment (MOE) of Korea in the form of Comprehensive Air Quality Index (CAI), which is trying to relate local air quality levels to individuals' health conditions.[5]

It is assumed that *I* in (2) is exogenously provided and thus is not subject to the individual's choices and does not explicitly enter the budget constraint. Therefore, while risk perceptions become endogenous outcomes, information is still considered an exogenous factor in the

[4] This assumption seems realistic to the extent that information about air pollution level may primarily affect frequency of health symptoms such as coughing, headaches or eye irritation, not the degree of discomfort or severity of illness associated with the pollution level (Berger et al., 1987).

[5] Comprehensive Air Quality Index(CAI) of Korea is currently measured by in-situ ground measurement stations in which the concentration levels of five major pollutants (O_3, PM, SO_2, NO_2, CO) are measured in more than 250 locations across the country every day. These concentration levels are then converted into CAI values using standard formulas developed by MOE. The CAI presents information about local air quality as easy to understand as the weather forecast by utilizing words, numbers and colors. MOE's AIRKOREA web site releases CAI information of five air pollutants in major cities every day. The CAI information also contains facts about the health and environmental effects of air pollution, and useful advices one can take to protect one's health. Moreover, if the concentration of some air pollutants (especially, O_3, PM and Asian dust) rises above the certain level in major cities, MOE and local agencies are issuing air pollution alert or warning through public media to inform sensitive groups of people about severity and duration of poor air quality. Recently several cities throughout the country have started providing air quality information through mobile phone text message service for those people who want to receive the text message service.

individual's decision process. Given the available information about air quality and corresponding health status, an individual is assumed to make consumption plans, *Y*, and self-protection decisions, *s*, which is expressed as the constrained expected utility maximization problem of (3) and (4);

$$\underset{Y,s}{Max}\, EU = (1-\pi(s,I))U(Y,z=0) + \pi(s,I)U(Y,z=1) \qquad (3)$$

$$\text{s.t.} \quad Y + ps = M \qquad (4)$$

where *p* is the price of self-protection and *M* is income. Solving the constrained expected utility maximization problem in (3) and (4) yields an expected value of indirect utility functions given as:

$$EV(p,M,I) = (1-\pi(s^*(p,I))V(M-ps^*, z=0) + \pi(s^*(p,I))V(M-ps^*, z=1) \qquad (5)$$

where s^* denotes an optimally chosen level of actions of self-protection.[6]

Now suppose that Korean government is planning to launch Geostationary Environmental Monitoring Satellite (GEMS), which, coupled with currently used in-situ ground level monitoring stations, will support the mission of improving monitoring of major air pollutants. In other words, satellite data collected from space, if GEMS is launched and implemented as planned, will improve the air quality information provided to the public by facilitating the accuracy of air quality monitoring and forecasting system.

The instruments and services of GEMS will have economic values to extent that the improved air quality information provided by the satellite data change individuals' health risk perceptions and consequently enhance the quality of decisions made by the individuals. Suppose

[6] Because of the exogeneity of information for the individual's decision process, marginal willingness to pay (MWTP) for additional information can be derived by taking the total differential of the ex ante indirect utility function, (5). The change of information that we consider is not complete but partial in the sense that the information affects households' risk perceptions while still leaving some uncertainty present. By setting dEV=0 and holding dp=dπ=0, we can solve for the income change that would be required in response to exogenous additional information to keep expected utility constant:

$$\frac{\partial M}{\partial I} = \frac{V(\cdot, z=0) - V(\cdot, z=1)}{(1-\pi)(\partial V(\cdot, z=0)/\partial M) + \pi(\partial V(\cdot, z=1)/\partial M)} \times \frac{\partial \pi}{\partial I} = MRS_{\pi M}\frac{\partial \pi}{\partial I} = \frac{\partial \pi/\partial I}{\partial \pi/\partial s}\, p = \frac{\partial(ps)}{\partial I}$$

The first two terms of the above MWTP expression captures both the direct effect of information on risk perceptions ($\partial\pi/\partial I$) and indirect effects through marginal values of changes in risk ($MRS_{\pi M}$). The last two terms can be derived with assumptions of a two-stage decision process in a household production framework (Deaton & Muellbauer, 1980). That is, in the first stage, the individual is minimizing self-protection expenditures to achieve a given level of health risk. In the second stage, the expected utility is maximized subject to the budget constraint that induces the self-protection expenditures from the first stage. In sum, the expression implies that the MWTP for information is equal to the marginal cost of acquiring information in terms of the increase in self-protection expenditures. Thus one doesn't need to observe the marginal rate of substitution *($MRS_{\pi M}$*) but can be derived with knowledge of technical relationship between *I* and *s* in the risk perception function. A more detailed derivation can be found in Eom (1995).

that data products from GEMS will improve the accuracy of air quality information so that *I* will change from I^0 to I^1. As long as air quality information is considered to be an economic service, the ex ante indirect utility function associated with the improved information, $EV(p, M, I^1)$, would be greater than that with information from in-situ ground monitors, $EV(p, M, I^0)$.

Suppose that the individual was asked in a contingent valuation (CV) survey whether he is willing to pay $A toward a space fund, which will be used to develop and launch GEMS, and eventually will generate data products to improve the accuracy of air quality information (from I^0 to I^1).

Following McFadden (1974) and Hanemann (1984), estimation of the individual's dichotomous choice (DC) question format of CV responses require random errors implying incomplete knowledge about the respondent's preferences from the perspective of the analyst. In this binary outcome case of 'yes/no' response, the individual would express 'yes' for the improved information only if

$$EV_1(p, M, I^1, \theta, \varepsilon^1) - EV_0(p, M, I^0, \theta, \varepsilon^0) > 0 \quad (6)$$

That is,

$$\Delta\overline{EV} = \overline{EV_1}(p, M, I^1, \theta) - \overline{EV_0}(p, M, I^0, \theta) > \varepsilon^0 - \varepsilon^1 = \varepsilon \quad (6')$$

where $\overline{EV_i}$ and ε_i indicate the deterministic and stochastic component of EV_i for response *i* ($i = 0,1$) in the view of the analyst. Assuming the difference in errors follows a normal distribution, a probit model can be used to explain the respondent's binary response of 'yes/no' in CV question. Extending the conventional practice of linear approximation for EV, equation (7) follows:

$$\begin{aligned}\Pr(yes) &= \Pr(\Delta\overline{EV} > \varepsilon) = \Pr(\alpha - \gamma_1 A + \gamma M + \eta S > \varepsilon) \\ &= \Pr(X'\beta > \varepsilon) = \Phi(X'\beta) \quad (7)\end{aligned}$$

where $\alpha = \alpha_1 - \alpha_0, \gamma = \gamma_1 - \gamma_0, \eta = \eta_1 - \eta_0$ and parameters' subscripts recognize the corresponding conditional indirect utility function with and without information from GEMS. *A* denotes the amount of space fund presented to the respondent in the CV question, while *S* designates a set of attitudinal and demographic variables as potential determinants of binary response. Finally, $\Phi(\cdot)$ represents a standard cumulative normal probability distribution.

Using parameter estimates of the linear random utility model in (7), one can measure each individual's willingness to pay for additional information from GEMS, A^*, which measures the maximum amount that the individual is willing to pay while holding the two conditional indirect utility constant as given in (8)

$$EV_1(p, M - A^*, I^1; S) = EV_0(p, M, I^0; S) \quad (8)$$

III. CV Study Design and Survey Data

As part of economic analysis to evaluate the environmental space project to improve air quality monitoring and forecasting, an in-person household survey of 1,000 randomly-selected residents throughout the nation was conducted during November of 2009. The sample of residents over 25 years old (excluding students) were allocated across major cities according to age and gender distribution of the sampling area. The survey design closely followed the recommendations made by NOAA panel, which was in charge of evaluating the use of stated preference methods for assessing the public's willingness to pay (Arrow et al., 1993). The CV survey question was reviewed by two focus groups and was pretested with 100 potential respondents, which provided information on the expected distribution of WTP.

As indicated earlier, GEMS is a payload of a multi-purpose geostationary satellite which is planned to be launched no later than the year 2017. GEMS is supposed to deliver data products that will enhance and improve monitoring and forecasting of air quality over Asian regions by providing air chemical species measurements with high temporal resolution; by enabling to monitor regional transport events such as trans-boundary transport of pollution and Asian dust; and by enhancing our understanding on interactions between air chemistry and meteorology (Kim, 2009).

Data products from GEMS coupled with those from in-situ ground measurement stations will provide more complete, timely and more reliable information about air quality. Closely consulted with Atmospheric scientists in our research team, additional data products from GEMS are expected to improve the accuracy of CAI approximately by 20% compared with using only ground measurement data.

It is notable that the contingent commodity being valued here is not improvement of adverse health effects (in terms of reduction in mortality and morbidity risk) from changes in air quality, but enhancement of air quality information. If the government successfully implements a policy to improve ambient air quality level, individuals can enjoy benefits of reduced health risks whether they realize it or not. However, the benefits from improved information about local air quality from GEMS may not be fully realized unless individuals recognize and utilize the information and incorporate them into their decision makings.

With no previous CV study identified in measuring value of information from space-derived earth science data, a due care was taken to understand earth scientific knowledge and translate them into layman's terms. Especially we presented three pages of information sheets describing the potential needs of launching GEMS and their main missions and potential impacts on individuals with several visual aids. Besides relating the potential benefits of data products from GEMS to improvement of air quality information and consequent impacts on individuals' health risks, we also presented additional effects of securing independent data products from GEMS. Accumulating the real time data associated with trans-boundary air pollutants will help Korean government to systematically cope with potential environmental conflicts among neighboring countries including China and Japan. Moreover, implementation of this space project on time will boost Korea's national image up to a leader in the area of geostationary environmental satellite because it will be the first attempt in the world to load a specialized environmental satellite.

To motivate respondents to focus on the CV questions, extensive information were collected on general attitudes toward air pollution, subjective perceptions about the accuracy of current air quality monitoring and forecasting system, perceptions about health risk from air pollution, and history of respiratory diseases. Following these attitude and perception questions, and reminding respondents to consider their household income and expenditures, respondents were asked if they would be willing to pay for the suggested amount for the space project. Following NOAA panel's recommendation to secure the incentive compatibility, a single-bounded closed-ended question format was used with six different bid points ranging from 26 cents to $1.72 per month and per household.[7]

[7] Dollar values were calculated at the exchange rate (1,160won/US$1) when the survey was conducted (November 2009).

Since services or information that will be provided from GEMS can be considered to be a public good, it seems natural for respondents to think that the government will fund the space project. Therefore, one alternative chosen for the payment vehicle in the CV questionnaire was additional annual mandatory charges, which will be deposited in a public fund (e.g., a space science development fund) and will be solely used to support the GEMS project and provide environmental information including local CAI forecast and air pollution warnings. As another alternative payment vehicle, we devised a more personalized payment mechanism reflecting recent services from several regional atmospheric environment agencies. The improved local air quality information generated from GEMS will be transmitted to the respondents by their cell phone text message service.[8] If the respondent is willing to pay for the additional charge for text message service of cell phones, the rest of the family may receive the environmental information service with free of charge. Those additional charges for cell phone bill will be deposited into a fund to support the space project**.**

After the WTP question, follow-up debriefing questions were asked to identify reasons for unwillingness to pay or some form of protest. After those debriefing questions, respondents were also asked to evaluate the degree of credibility of the CV scenario, especially in terms of the stated improvement in the accuracy of air quality information.

Reflecting the two different payment vehicles, we designed two versions of CV question: monthly charges for the space science fund (Type A) and monthly charges for text message services of cell phone bill (Type B). The payment frequency for charges was designed to be monthly to be in accordance with the cell phone bill payment scheme. Payment term was defined to be the following five years, implying a finite funding obligation. The whole sample was split into two groups with 500 respondents for each groupof Type A and Type B. Within these two independent samples, each sub-sample is split into two groups again depending on respondents' health status. 30% of the sample in each group was allocated for sensitive groups of population, who have experience of respiratory diseases and/or are elderly people over 60 years old. Cooperation rate, which is defined as the number of interviews that were completed once respondents met the screening criteria, were approximately 43%.

Of 7 categories for the debriefing questions followed by the dichotomous WTP elicitation question, the following 3 categories considered protest response because those categories do

[8] As indicated it earlier, part of the country including Seoul metropolitan area have already started the text message service to inform CAI and air pollution alert/warnings. Thus it seems that cell phone message may serve as a realistic payment vehicle for eliciting individuals' WTP for environmental information.

not reflect respondents' true WTP: (1) the government should pay for this project with taxes already collected for Type A group, and cell phone bill is already too high for Type B group; (2) there is not enough information to answer; (3) I do not believe that the space project will succeed. About 36% of the response were judged to be protest respondents, constituting a substantial portion of 'no' bids (Mitchell and Carson, 1989). If there exist systematic differences between respondents who participate in the WTP question and those who protest, using all the sample without considering this possibility will introduce sample-selection bias in estimating WTP functions as respondents with very low or very high WTP will self-select themselves into the sample. Table 1 defines the variables used in the analysis and provides summary statistics.

IV. **Empirical Results**.

Table 2 reports the parameter estimates of WTP models differentiated with estimation methods and covariate specifications related to the effects of experimental design variables, respondents' attitude and socio-economic variables. Models (1) and (2) utilized the full sample without taking into account the potential effects of protest bids, and estimated respondents' intentions to support the space program in a form of single-bounded dichotomous choice, which was estimated via maximum likelihood estimation using LIMDEP Version 9.0.

Among three experimental design variables for CV question as presented in Model (1) of Table 2, two design variables, BID and PVEHICLE, significantly influenced WTP function. First of all, the bid amount presented to the respondents (BID) exhibited the negative signs across all the model specifications, indicating that the tendency for the 'yes' responses diminishes with the offered bid amount. The PVEHICLE variable indicated significant positive signs across model specifications, demonstrating that payment vehicles have different effects on respondents' intentions.

It is notable that the personalized payment vehicle, i.e., the additional cell phone bill, elicited a lower WTP for the improved information from GEMS than collective charges for the space fund.[9] Contrary to our expectation, the SENSITIVE GROUP variable in Model (1) had

[9] In fact, mean WTP of the sub-sample with additional fee for text message service of cell phone counted only 40% of that of the sub-group with additional charge as an objective tax. The reason for this striking difference requires further investigation, which we will leave for a further study.

positive sign but was not significant, implying no significant differences in intentions to express WTP for improved information across different groups of health conditions. Combined with the results from participation decision on CV response in the first column of Model (3), respondents' health conditions did not seemed to influence their inclination to express WTP for improved information once they decided to participate in the CV response.

The results for experimental design variables in Model (1) remained similar in Model (2) with more covariates. Overall, most covariates included had significant effects on WTP function. The subjective attitude toward accuracy, which is measured by AQIAccuracy variable, about the current air pollution forecast and warning system had negative impacts on the probability of saying 'yes' to given bid amount. In other words, as respondents think that the current comprehensive air quality index (CAI) works well, they seemed to be less inclined to be willing to pay for improving information by launching GEMS.

Equally important, the subjective beliefs on health risks from air pollutants had a significant positive influence on WTP. As expected, respondents' attitudes toward public investment for space development program in general have also positive impact on the stated preference for launching GEMS. Higher income group of respondents with more children were more likely to express their support for the project. Respondents who get regular health check-up were also more inclined to say 'yes' to specified bid amount.

A selection model was applied to take account of effects of potential protest bid responses, as presented in Model (3) of Table 2. That is, treating decisions to participate in the CV response as part of joint decision process with the valuation of space project, a two-step estimation procedure was employed to estimate determinants of both participation and CV responses.[10] First, respondents would contemplate whether to reveal their preferences, i.e., to participate, or not, i.e., to protest. Then, second step estimation model was only applied to respondents who indicated they would participate in the CV response. An inverse Mills' ratio has been included in the second column of Model (3) as a correction term for effects induced by the sample selection. The inverse Mills' ratio (λ) was calculated using the parameter estimates of the probit model describing participation on the CV response, as shown in the first column of Model (3). Sensitive groups of high income respondents who are residing in the Seoul

[10] White's (1982) development of the asymptotic properties of quasi-maximum likelihood estimators provides the justification for our adaptation of Heckman (1979) selection rule to this case. White's analysis established that when the true model and the mis-specified model are identical for certain parameter values, ML estimates from the mis-specified model are consistent. See Messonnier et al., (2000) for an application of this two-step estimation method for the dichotomous choice format on the CV questionnaire.

metropolitan area were more likely to participate in the CV question and express their preferences for environmental information.

With respect to the selection effects, the inverse Mills' ration, λ, in Model (3) had statistically significant positive sign, which indicates evidence of selection bias by not accounting protest bids. It is interesting to observe that the parameter estimate of AQIAccuracy variable in Model (3), although showing the expected sign, became statistically insignificant with the inclusion of λ, as compared with that of Model (2).

Using the parameter estimates of probit models reported in Table 2, welfare measures of improved information from GEMS are presented at the bottom of Table 2. As indicated earlier, the source of improvement in information arises from the 20% increase in the accuracy of air quality monitoring and therefore air quality forecasting by launching GEMS. When we used the entire sample without accounting protest bids, annual mean WTP per household was stable at about \$3.70 across Models (1) and (2). On the other hand, when we utilized parameter estimates from two-step procedure in Model (3), annual mean WTP estimate was calculated to be \$7.14, which was almost twice of those estimated from the models that do not account for protest bids.

IV. Concluding Remarks

The main objective of this paper was to measure for the first time the potential economic values of improved air quality information that may be realized from data products provided by a payload of a multi-purpose geostationary satellite (GEMS). We have presented a theoretical model to incorporate information into individual's utility maximizing behavior as well as empirical results based on contingent valuation survey. In doing so, we tried to apply both full sample and sample selection models to empirically test whether respondents' protest bids affect willingness to pay estimation. In addition, we attempted to empirically test the hypothesis that individuals' stated WTP for public goods might differ based on the way in which the good is funded. The two payment vehicles comprise a coercive charge and a personalized fee.

Due to lack of similar contingent commodity in non-market valuation, our contingent valuation study put an extensive effort in designing a plausible and credible CV questionnaire. Empirical results, which are estimated using a survey data from 1,000 randomly-selected households, suggest that relevant attitudinal and demographic variables as well as economic variable (BID and MINCOME) had significant effects on WTP for improved environmental information. This result supports our basic premise that people value better environmental information, which can have potential positive impacts on public health by allowing individuals to adjust their decision making to avert from negative effects of air pollution.

Estimating a sample selection model revealed the existence of selection bias if protest bid responses are neglected. Annual mean WTP was estimated to be almost twice as high in the sample selection model compared to the estimate when full sample was used.

Interestingly, the coefficient of a dummy variable representing the payment vehicle of mandatory charge had significant positive sign regardless of model specifications, which implies stated willingness to pay is strongly affected by the choice of payment vehicles. This result requires further investigation, which we will leave for our subsequent research subject.

References

Anderson, B. Holt, *GMES Service Element PROMOTE: C2 Cost Benefit Analysis for Service Portfolio Version 2.0*, European Commission, 2006

Arrow, K., R. Solow, P. Portney, E. Leamer, and R. Radner, and H. Shuman, "Report of the NOAA Panel on Contingent Valuation," *Federal Register*, US. Department of Commerce, National Oceanic and Atmospheric Administration. Vol.58, (January 15), 1993, 4601-4614.

Brent, R., *Applied Cost-Benefit Analysis*, Edward Elgar Press, 1995.

Carson, R., "Contingent Valuation: Theoretical Advances and Empirical Tests since the NOAA Panel," *American Journal of Agricultural Economics*, Vol.79, 1997, 1501-1507.

Chang, Y.K., *Feasibility Study of the next Geostationary Mission*, Korea Aviation University, Aug. 2008 – Feb. 2009, MEST.

Comprehensive Air Quality Index (CAI), http://www.airkorea.or.kr, since 2005.

Cook, P.J. and D.A. Graham, "The Demand for Insurance and Protection: The Case of Irreplaceable Commodities," *Quarterly Journal of Economics*, 91, 1977, 143-156.

Deaton A.S. and J. Muellbauer, *Economics and Consumer Behavior*, Cambridge University Press, 1980.

Eom, Y.S., “Self-Protection, Risk Information, and Ex Ante Values of Food Safety and Nutrition,” in *Valuing Food Safety and Nutrition,* (ed.) by Julie A. Caswell, Westview Press, 1995.

Eom, Y.S. and J.H. Hong, “Identification and Correction of Protest Responses in the Willingness to Pay Estimation for Public Project Feasibility Analysis,” *Korean Journal of Public Finance,* Vol. 24, No.4, 2009.

EPA, *Guidelines for Preparing Economic Analysis*, USA, 2000

European Space Agency, *Socio-Economic Benefits Analysis of GMES*, 2006

Hackl F. and g.J. Prickner, “Warm Glow, Free-riding and Vehicle Neutrality in a Health-Related Contingent Valuation Study,” *Health Economics*, 14, 2005, 293-306.

Hanemann, W., “Welfare Evaluations in Contingent Valuation Experiment with Discrete Response,” *American Journal of Agricultural Economics*, Vol.66, 1984, 332-341.

Heckman, James J., “Sample Selection Bias as a Specification Error,” *Econometrica*, 47, 1979, 153-161.

Greene, W., *LIMDEP-Version 9.0*, Econometric Software, INC. 2005.

Kim, J., *Feasibility study of Geostationary Environment (AQ) Monitoring Mission*, Research Report submitted to Ministry of Environment of Korea, 2009.

McFadden, D., “Conditional Logit Analysis of Qualitative Choice Behavior,” in *Frontiers in Econometrics,* (ed.) by P. Zarembka, Academic Press, New York, 1974.

Messonnier, M.L., J.C. Bergstrom, C.M. Cornwell, R.J. Teasley and H.K. Cordell, “Survey Response-Related Bias in Contingent Valuation: Concepts, Remedies, and Empirical Application to Valuing Aquatic Plant Management,” *American Journal of Agricultural Economics*, 80, 2000, 438-450.

Mitchell, R.C. and R.T. Carson, *Using Surveys to Value Public Goods: The Contingent Valuation Method,* Resource for the Future, Washington D.C., 1989.

NOAA, USA, *An Investigation of the Economic and Social Value of Selected NOAA Data and Products for Geostationary Operational Environmental Satellites(GOES)*, 2007

Strazzera E, M. Genius, R. Scarapa and G. Hutchinson, "The Effect of Protest Votes on the Estimates of WTP for Use Value of Recreational Sites," *Environmental and Resource Econometrics*, Vol.25, 2003, 461-476.

White, Halbert, 1982, “Maximum Likelihood Estimation of Mis-specified Models,” *Econometrica*, 50(January): 1-26.

Wiser, R.H. “Using Contingent Valuation to Explore Willingness to Pay for Renewable Energy: A Comparison of Collective and Voluntary Payment vehicles,” *Ecological Economics,* 62, 2007, 419-432.

<Table 1> Definitions of Variables and Sample Characteristics

Variable Name	Description	Mean (S.D)
Experimental Design Variables		
BID	The amount of charges presented in the CV scenario ($)	0.85 (0.48)
PVehicle	=1 if payment vehicle was monthly charges for a space science fund; 0 for monthly fee for text message service of cell phone	0.5 (0.5)
Sensitive Group	=1 if respondent is over 60 years old or has some respiratory diseases; =0 for otherwise	0.3 (0.45)
Attitudinal Variables		
AQIAccuracy	Subjective perceptions about the accuracy of the current CAI information system on the 1-100 scale	62.4 (16.6)
APRisk	1 to 10 seriousness index of health risk from exposure to air pollutants	7.9 (1.4)
ESInvestment	=1 if respondents think that more public fund should be allocated to the space projects; 0 otherwise	0.64 (0.48)
CVSAgree	=1 if respondents think that the CV scenario presented is plausible; 0 for other wise	(0.53) (0.47)
Socio-demographic variable		
MInomce	Household's before tax 2008 monthly income (1,000$)	3.148 (1.401)
# of Children	Numbers of children under age 13	0.41 (0.439
Work	=1 if the respondent is working; 0 otherwise	0.78 (0.43)
HCheck	=1 if the respondent gets regular health check-up	0.37 (0.48)

<Table 2> Probit Estimates of CV Participation and WTP Functions

	Full Sample Estimation		two-step Estimation	
	Model 1	Model 2	Model 3	
			Participation	WTP
Intercept	0.137 (1.388)[a]	-0.554 (-1.617)	0.094 (0.751)	-0.494 (-2.176)
Bids	-0.876 (-9.331)	-0.895 (-9.336)		-0.997 (-8.503)
Payment Vehicle	0.269 (3.162)	0.259 (2.991)		0.348 (3.268)
Sensitive Group	0.0145 (0.360)		0.144 (1.619)	
Attitude Variable				
AQIAccuracy		-0.00475 (-1.850)		-0.00289 (-0.916)
APHRisk		0.0604 (1.875)		0.107 (2.797)
EsInvesment		0.314 (3.390)		0.317 (2.803)
Socio-demographic Variable				
Mincome		0.0560 (1.647)	0.062 (1.882)	0.0799 (1.643)
Seoul Residents			0.169 (2.063)	
Gender			-0.113 (-1.375)	
# of Child		0.179 (3.047)		0.233 (3.196)
HCheck		0.180 (2.015)		0.298 (2.631)
IMR lamda				0.438 (1.842)
N	1,000	1,000	1,000	642
Psuedo R^2	0.09	0.11	0.08	0.16
Prop. of correct prediction	71.2	71.8	67.7	71.2
Annual Mean WTP for the sample	$3.78	$3.71		$7.14

[a] The numbers in parentheses below the estimated coefficients are the ratios of the estimated coefficient to the estimated standard error

Development of G-CEEP (Glocal Century Energy Environment Planning) Model and Case Study Analysis

- Evaluation of introducing carbon tax in China

Xuanming Su[1*], Hongbo Ren[2], Weisheng Zhou[1], Ken'ichi Nakagami[1] and Hailin Mu[3]
1: Graduate School of Policy Science, Ritsumeikan University
2: Ritsumeikan Global Innovation Research Organization, Ritsumeikan University
3: School of Energy and Power Engineering, Dalian University of Technology
**ps0040hv@ed.ritsumei.ac.jp*

Abstract

This study develops an integrated low carbon evaluation energy model named Glocal Century Energy Environment Planning Model (G-CEEP) for analyzing the potentiality for building a low-carbon society among China, Japan and Korea. This paper provides an analysis of each region of China by imposing a series of carbon tax to evaluate the energy consumption structure, CO_2 emission and induced effect of other energy related emissions such as SO_2, NO_X.

Keywords: *low-carbon, energy model, CO_2 tax*

1. Introduction

The realization of low-carbon society is recognized as the common goal among the whole world including both developed and developing countries. Using energy model is an efficient way to analyze the feasibility of building such a low-carbon society. Generally, there are two fundamental approaches for energy modeling dealing with such energy policies and environment issues: top-down and bottom-up. Also, there is another modeling approach, the hybrid energy model, which combines the top-down and bottom-up approaches.

Top-down models evaluate the system from aggregate economic variables, whereas bottom-up models consider technological options or project-specific climate change mitigation policies [1]. The GEM-E3 world model is a full-scale computable general equilibrium model for the world economy, which provides details on the macro-economy, and its interaction with the environment and the energy system. The model has multi-nation, multi-agent, multi-sector, and dynamic features. It primarily provides a top-down approach on the world economy [2]. DNE21 is an integrated assessment model, composed of three sub-models: an energy system, a macro-economic and a climate change model. DNE21 is an optimization model, and its energy supply system is formulated in bottom-up fashion with about 50 kinds of technologies, developed by Research Institute of Innovative Technology for the Earth (RITE) [3]. Model for Analysis of Energy Demand (MAED) is an MS-Excel-based bottom-up energy demand analysis model. It evaluates future energy demands based on medium- to long-term scenarios of socioeconomic, technological and demographic development. Energy demand is disaggregated into a large number of end-use categories corresponding to different goods and services [4]. MARKAL is a dynamic linear programming, bottom-up, energy planning model allowing detailed representation of energy technology options on both demand and supply side of the energy system [5]. LEAP, the Long range

Energy Alternatives Planning System, is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. LEAP supports a wide range of different modeling methodologies: on the demand side these range from bottom-up, end-use accounting techniques to top-down macroeconomic modeling [6]. Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) is a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development (Messner and Strubegger, 1995 [7]). It combines a top-down description of the economy and energy demand with a bottom-up description of the energy sector.

As the major economic entities in the Northeast Asia, China, Japan and Korea lead the economy development of Asia. The economies of the three countries are dynamic, resilient and closely interlinked. They share common challenges as well as opportunities. According to the Energy Information Administration, in 2007, the primary energy consumption of China, Japan and Korea share 67.3% in the Asia & Oceania, 22.7% in the world [8]. For transforming into a low-carbon society, it is necessary to build an energy model among the above 3 countries.

2. Glocal Century Energy Environment Planning model

This study is prepared based on China, Japan and the Republic of Korea's current economic status and energy consumption. It takes the energy constraint in the process of production, transportation and consumption, and their balancing relation as a master line, establishes a large scale linear optimization programming model, Glocal Century Energy Environment Planning (G-CEEP) model, implements analytic calculation on the above three countries' energy consumption and greenhouse gas emission, and focuses on the analysis of the potentiality for building a low-carbon society among China, Japan and Korea.

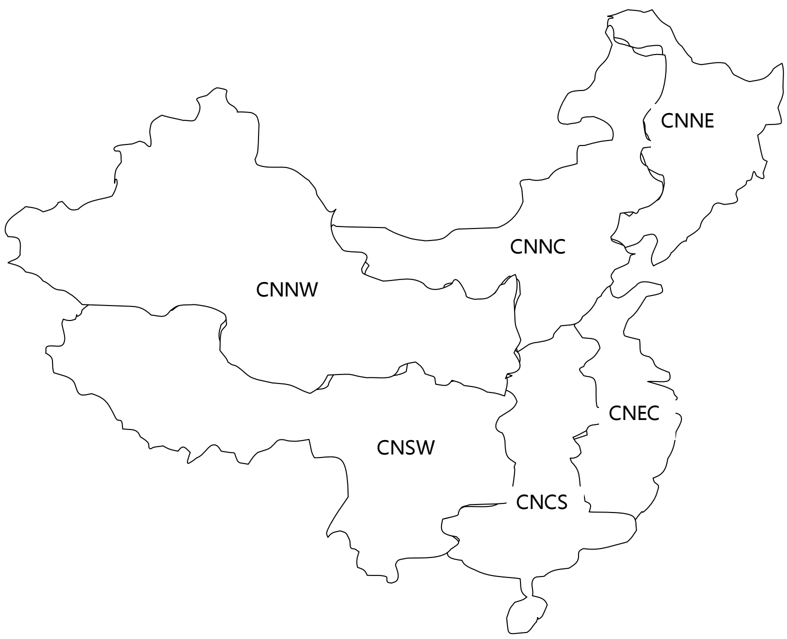


Fig.1 Regions division of China

The time span for G-CEEP model is from 2000 to 2100. Taking into account the energy resources of different regions of the same country and the diversity of energy demand, the model divides China into six regions as shown in Fig.1. There are North China (CNNC), Northeast China (CNNE), East China (CNEC), Central and South China (CNCS), Southwest China (CNSW) and Northwest China (CNNW).

G-CEEP model stems from a series of basic database related to production, transportation and consumption for energy, which mainly covers regional table, time span table, energy carrier table, energy conservation and storage technology table, energy transportation way table, energy transportation path table, list of demanding sectors, electric power peak table and environmental burdens table. Besides, characteristic data tables relating to the characteristics of each technology are included as well: technical characteristic data table, technical storing data table, resource mining data table, land use data table, city waste treatment rate data table, power system related data table, energy transportation data table, demand and consumption data table, and environmental emission data table. The relevant data comes from "China Statistical Yearbook" [9], "China Energy Statistical Yearbook" [10], the statistical yearbooks from each province of China, "World Economic Yearbook" [11], and part of data comes from the statistical results of Japan Institute of Advanced Industrial Science and Technology (AIST) and Energy Information Administration (EIA) of America.

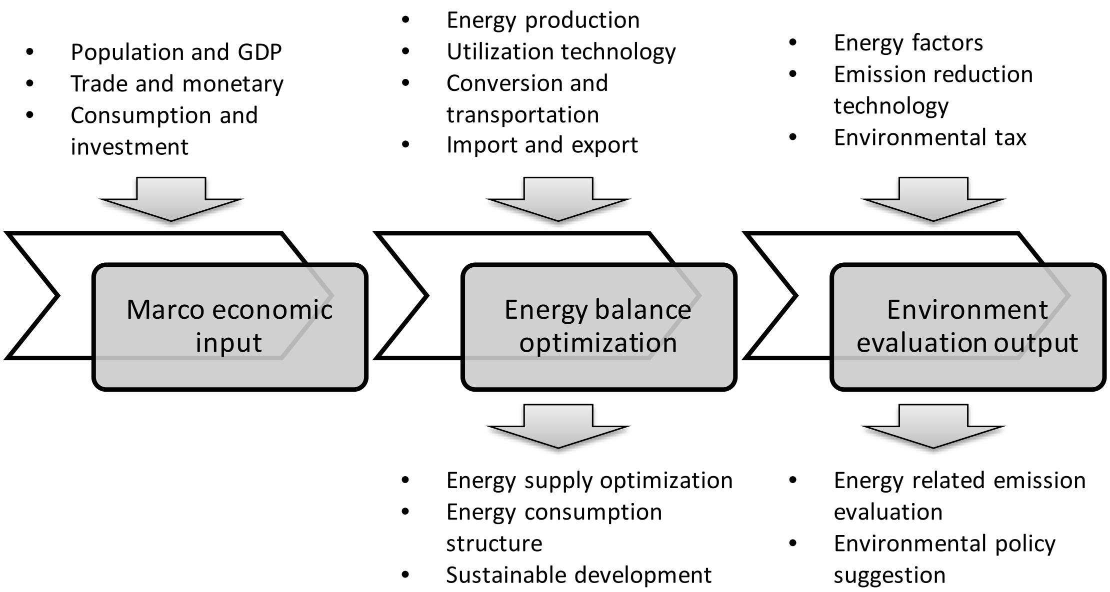


Fig.2 Flow chart of G-CEEP model

G-CEEP model is an integrated model which mainly includes three portions: the macro-economic input, the energy optimization model and the environment evaluation output (Fig.2). The environment evaluation output is to calculate the emission of CO_2, SO_2 and NO_X under specific scenarios, through emission factors of different energy technologies based on the energy optimization model and under relevant environment policy constraints. The object of the energy system is to minimize the total system cost. The total cost is indicated as the sum of energy cost, imported equipment cost and final recovery cost of equipment that are classified. When considering the impact attendant of environment taxes to the energy system, it takes environment taxes cost as a part of the system cost, optimizes the target function of the system cost, and figures out the physical volume of each compounded element under optimized state.

$$T_{COST} = \sum_n \sum_t \delta_t \times (MAI_{t,n} + NEW_{t,n} + REC_{t,n} + IMP_{t,n} - EXP_{t,n} + \sum_i \rho_i EMI_{i,t,n}) / (F_n \times F_{GDP}) \quad (1)$$

T_{cost}: Total system cost.

δ_t: Conversion coefficient of current monetary value for t period, $\delta_t = 1/(1 + RATE_{dis})^t$ and $RATE_{dis}$ is the discount rate.

$MAI_{t,n}$: Annual maintenance cost for n region and t period.

$NEW_{t,n}$: Annually added new equipment construction cost for n region and t period.

$REC_{t,n}$: Recovery cost for n region and t period.

$IMP_{t,n}$: Cost for energy input of n region and t period.

$EXP_{t,n}$: Cost for energy output of n region and t period.

ρ_i: Environmental tax, i = 1, 2, 3 represents CO_2, SO_2, NO_x emission respectively.

$EMI_{i,t,n}$: Energy related emissions.

F_n: Exchange rate.

F_{GDP}: GDP deflator.

3. Model assumption

In the model, the population and GDP are considered as impact factors. The model adopts the estimated population result provided by Japan Center for Economic Research [12]. The population in China will reach 1.416 billion by 2020 which is top most and decease to 1.262 billion by 2050. The population in Japan will decrease from 0.126 billion in 2010 to 0.094 billion in 2050. The population of South Korea also reaches its top most at 48.514 million by 2020, and decrease to 39.043 million by 2050 as shown in Fig.3. Besides, GDP is also an important element impacting energy production and consumption. In accordance with the research results given by EIA[5], it indicates that by 2030, the GDP in Purchasing Power Parity in China, Japan and South Korea will reach 33.39, 4.99, 2.03×10^3 billion in 2000 USD respectively, which is shown in Fig.4.

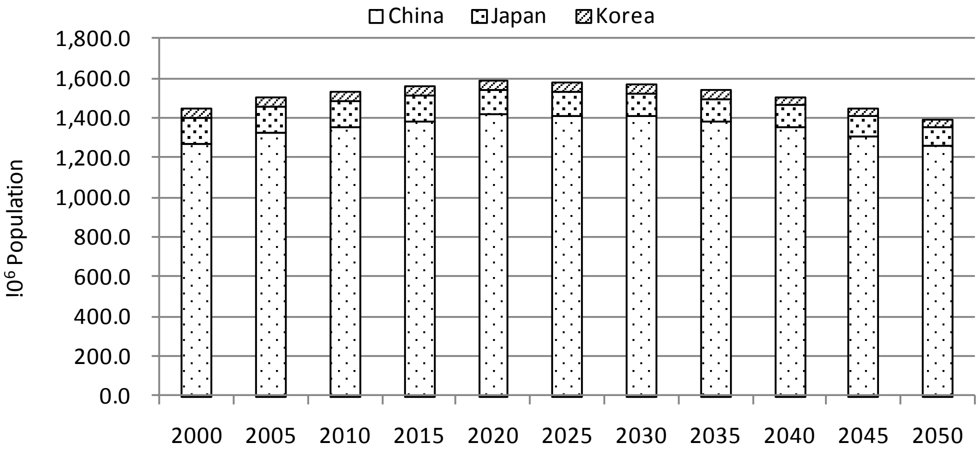


Fig.3 Future population growth trends

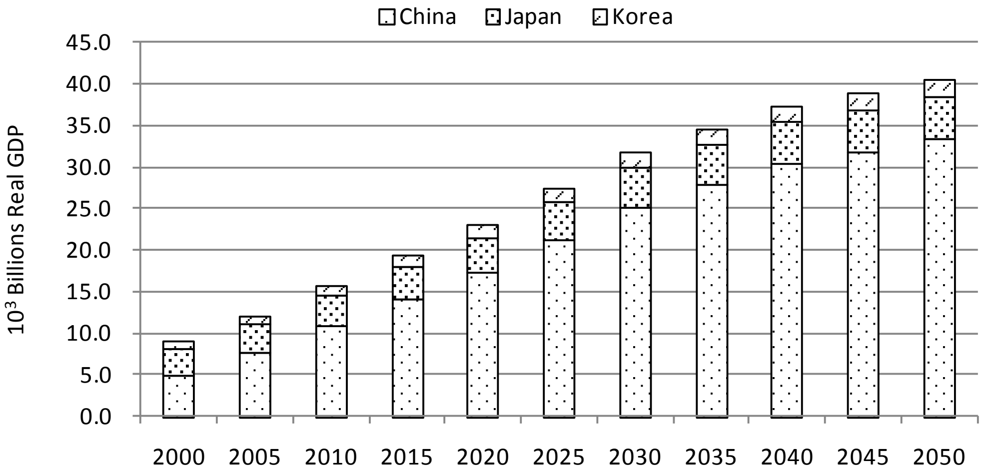


Fig.4 Future GDP in purchasing power parity

4. Results and discussions

This paper provides an analysis of each region of China by imposing a series of carbon tax: 0, 10, 20, 30, 40, 50, and 60 dollars (in 2000 USD) per ton carbon to evaluate the energy consumption structure, CO_2 emission and induced effect of other energy related emissions such as SO_2, NO_X during the selected time span from 2010 to 2050.

North China is a traditional heavy industry base which consumes most of the primary energy. Central and South China ranks 2nd following North China in the consumption of primary energy among the 6 regions in the model as showed in Fig 5. It chooses a representative tax value of 0, 20, 40 dollars (in 2000 USD) per ton carbon for comparing analysis. The figure shows that the total primary energy consumption will decrease in all of the regions after imposing related carbon tax. The larger tax is imposed, the more reduction of primary energy consumption will realize.

In terms of the energy consumption structure, this paper has representatively selected the year of 2030 to analyze different primary energy share in total energy consumption, as shown in Fig. 6. The proportion of coal consumption are 73.0%, 8%, 15.1%, 8.6%, 65.2% and 62.1% in North China, Northeast China, East China, Central and South China, Southwest China and Northwest China respectively. These will decrease to 69.4%, 1.7%, 12.0%, 2.1%, 55.4% and 57.8% after imposing $40 carbon tax. At the same time, the increasing oil and natural gas consumption in all the regions of China is remarkable. Also, in Southwest and Northwest China, the consumption of renewable energy was increasing rapidly. This is because in the vast area of Southwest and Northwest China, it is appropriate to develop the renewable energy such as solar power, wind power and biomass.

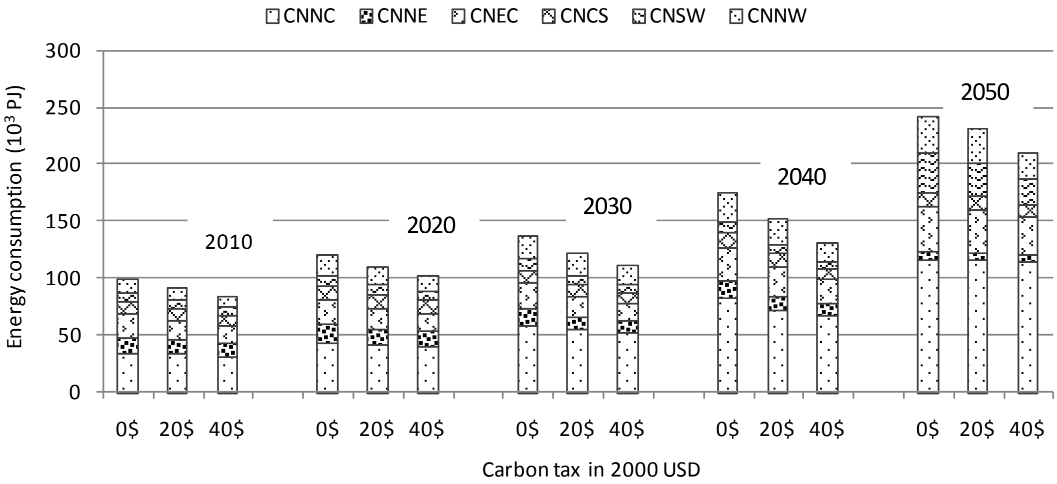


Fig.5 Primary energy consumption of 6 regions of China

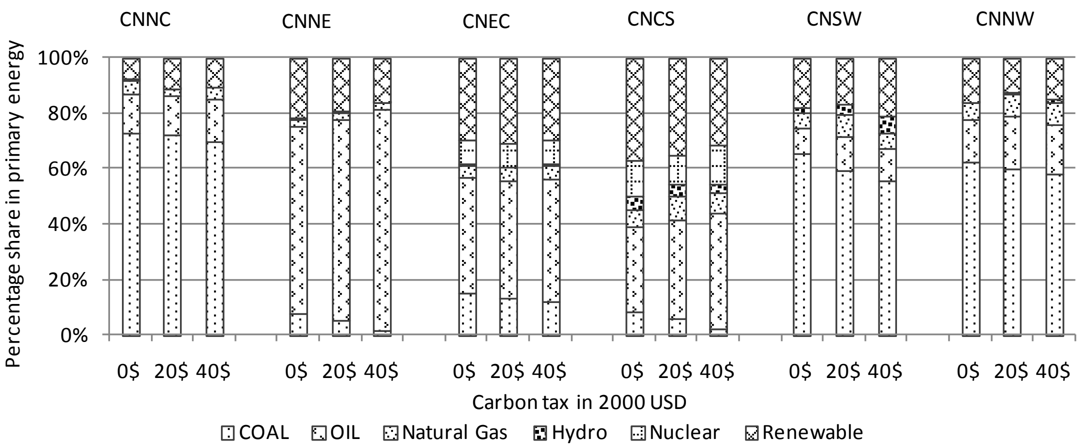


Fig.6 Energy consumption structure of 6 regions of China in 2030

Fig. 7 is the chart for CO_2 emission of 6 regions of China. The CO_2 emissions are 1008.8, 177.9, 272.1, 88.5, 133.3 and 317.5 $\times 10^6$ tons carbon in North China, Northeast China, East China, Central and South China, Southwest China and Northwest China in 2030. These will decrease to 952.0, 111.4, 187.3, 60.9, 91.7, 257.2$\times 10^6$ tons respectively after imposing $40 carbon tax.

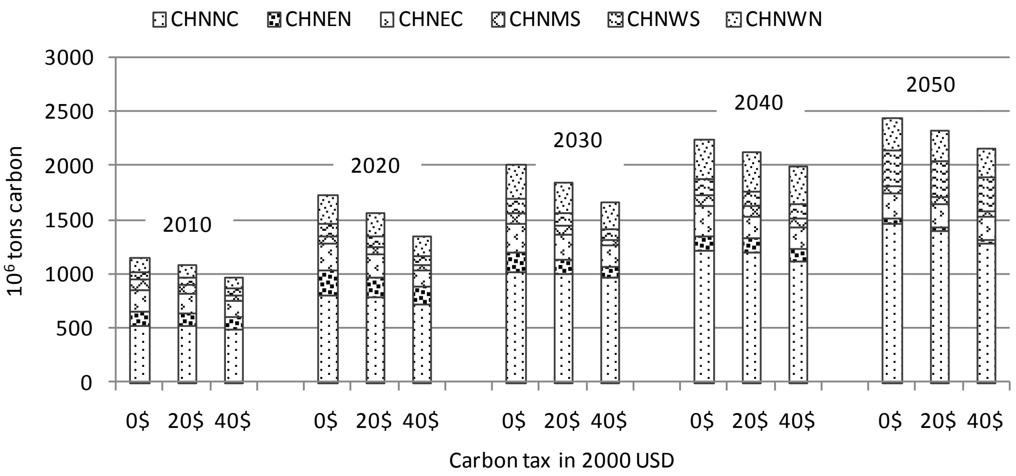


Fig.7 CO_2 emissions of 6 regions of China

Fig. 8 is the chart for induced effect after imposing CO_2 tax and related system cost. The figure shows that the effectiveness of carbon tax not only limits in the reduction of CO_2 itself, but also has a significant effect of other energy related emissions such as SO_2 and NO_X. The decreasing percentage of these emissions are larger than CO_2 itself. For example, if the tax value is \$40, the decreasing percentage of CO_2 is 5.2%. But the decreasing percentages for SO_2, NO_X are 18.1%, 23.2%. Because the coal, which is the "culprit" of energy related emissions, decreases rapidly after the imposing of carbon tax and the desulfurization and denitrification process are easier and more efficiency than CO_2 reduction. So the decreasing percentage trend for SO_2, NO_X are sharper than CO_2.

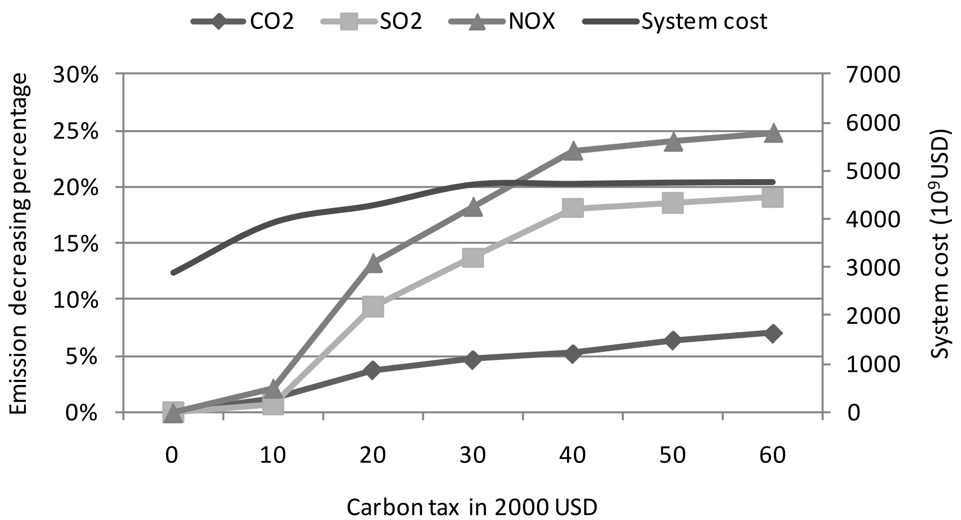


Fig.8 Induced effect after imposing CO_2 tax of China

5. Conclusions

This paper develops an integrated low carbon evaluation energy model named G-CEEP model and provides an analysis of each region of China by imposing a series of carbon tax to evaluate the energy consumption structure, CO_2 emission and induced effect of SO_2 and NO_X. The result shows that the energy consumption and related emissions are different for each region of China. For reducing CO_2 emission, different regions may adopts different strategy to ensure self-support of energy and build local low-carbon economy at the same time.

Acknowledgements

This research has been supported by Japanese Ministry of the Environment (Global Environment Research Fund, E-0804).

References

[1] IPCC, Climate change 2001: mitigation: contribution of Working Group 3 to the third assessment report of the Intergovernmental Panel on climate change. Cambridge: Cambridge University Press; 2001.
[2] Haoran Pan, "The cost efficiency of Kyoto flexible mechanisms: a top-down study with the GEM-E3 world model", *Environmental Modeling & Software*, Vol.20, 2005, pp.1401–1411.
[3] K.Akimoto, T.Tomoda, Y.Fujii, K.Yamaji, "Assessment of Global Warming Mitigation Options with Integrated Assessment Model DNE21", *Energy Economics*, Vol.26, 2004, pp.635-653.
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Model for Analysis of Energy Demand (MAED-2) User's Manual, VIENNA, 2006.
[5] Fishbone and Abilock, 1981 L.G. Fishbone and H. Abilock, MARKAL, a linear-programming model for energy systems analysis: technical description of the BNL version, International Journal of Energy Research 5 (1981), pp. 353–375.
[6] C. R. Weisbin, R. W. Peelle and R. G. Alsmiller, Jr., An assessment of The Long-Term Energy Analysis Program used for the EIA 1978 report to Congress, Energy, Volume 7, Issue 2, February 1982, Pages 155-170.
[7] Messner, S. and Strubegger, M., 1995: User's Guide for MESSAGE III, WP-95-69, International Institute for Applied Systems Analysis, Laxenburg, Austria.
[8] Energy Information Administration, International Energy Outlook 2009, May 27, 2009.
[9] China Statistics Press, "China Statistical Yearbook" annual edition for 1990-2008, China Statistics Press.
[10] National Bureau of Statistics Industrial Transportation Statistics Division, "China Energy Statistical Yearbook" annual edition for 1991-2007, China Statistics Press.
[11] Chinese Academy of Social Sciences, "World Economic Yearbook" annual edition for 1990-2008, Economic Science Press.
[12] Japan Center for Economic Research, Demographic Change and the Asian Economy, January 17, 2007.

Building Dynamic Adaptive Decision Framework of Integrated Resources under Sustainable Power Development

Shao-Pin Hung, National Taipei University[1]
Ssu-Li Chang, National Taipei University[2]

A B S T R A C T

Facing drastic global climate changes, the whole world has put lots of effort into pursuing energy savings and carbon reduction to achieve a common goal - sustainable development, especially in the electricity sector which is one of the cores for sustainability. However, due to the gap between the carbon reduction target and Business As Usual (BAU) emissions, as well as other uncertain factors such as technological innovation, the fluctuation of energy prices and demand, and reform of energy regulation, the complicated system of power infrastructure needs to proceed with adaptive control to accommodate future possible structural change. The scope of adaptive change includes choices from a dynamic and flexible mix of power technologies, the business model of power demand and supply, the design of the related institutional system and the establishment of a dynamic decision mechanism. These choices contribute to power-based sustainable development that will facilitate an intelligent low-carbon society.

This study adopts the “adaptive control theory” as the major approach which evolved from the optimal control through to the stochastic optimal control and then to the stochastic adaptive optimal control. Complex, dynamic and feedback characteristics that originated from ecological, circular, and evolutionary economics are incorporated, together with methods of decision processes in which a system’s self-organization capability and feedback effects are taken into account. In the end, the proposed approach is applied to the electric power business-focused operational system with integrated resources, which includes the adaptive evolution of the electric power-based integrated resources, the eco-industrial park and industrial symbiosis-based integrated resources, and the land sustainability-based integrated resources.

This study intends to construct a framework for the dynamic adaptive decision models of integrated resources under sustainable power development. Three

Note [1]: Doctoral Student of Institute of Natural Resources Management , National Taipei University, u827131@taipower.com.tw
[2]: Professor of Institute of Natural Resources Management , National Taipei University, ssuli@mail.ntpu.edu.tw

objectives can be summarized. First is to design the dynamic programming decision context, considering the external and internal factors affected by mitigation and adaptation strategies based on dynamic integrated resources planning. Second, it aims to build a sustainable indicative system including the adaptive and sustainable 3E indices, and develop risk assessment models for assets under deterministic, stochastic and dynamic scenarios, respectively. Finally, it builds a dynamic multi-agent co-opetition clouding network system for dynamic simulations which provide the dynamic adaptive optimal decisions and take into account just-in-time, just-in-place and just-in-context scenarios for sustainable development.

The preliminary results of simulation from the case study are summarized as follows:

I. Under the weak sustainability scenario reflected by low sustainability with a low adaptive indicator and low value with high risk objective condition, the reduction of carbon released from power infrastructure is required through a portfolio of resources, including: (1) adaptively increasing the control capability of the smart grid, (2) adaptively decreasing the use of fossil fuel generation resources, (3) adaptively increasing renewable generation resources, (4) adaptively increasing demand-side management (DSM), and (5) adaptively reducing carbon emissions through carbon assets management.

II. Under the moderate sustainability scenario reflected by moderate sustainability with a middle adaptive indicator and middle value with middle risk objective condition, in addition to the aforementioned change of power infrastructure, it will impact economic growth and lead to industrial structure change.

III. Under the strong sustainability scenario reflected by high sustainability with a high adaptive indicator and high value with low risk condition, it will result in a significant decrease in economic growth due to adaptive limitations associated with carrying capacity and ecological footprint for the land use.

1. Introduction

In the face of the pressure resulting from the greenhouse effect and sustainable development, many theoretical ideas regarding business model and application tools were brought into existence. While environmental economics emphasizes the internalization of environmental externalities, it is still fundamentally based on and subject to neo-classical economic theory and limitations, that is, from the standpoint of an economist to govern the economic system according to equilibrium theory. Under this situation, resources and the environment are regarded as exogenous factors of economic systems. It is therefore a weak sustainability development model. On the other hand, ecological economics attempts to integrate the ecosystem and the economic system and to observe interaction and feedback between these two systems from a systematic viewpoint. Under this situation, because the resources and environment are endogenous factors, the system can be classified as a moderate sustainability development model. In addition, the circular economics is based on an ecological economics view of regional economics, from a practical viewpoint of the 3 R's of resource reduction, recycling and reuse, further strengthening the cyclical and feedback nature of ecological economics, as well as its microscopic and realistic characteristics, i.e., from the circular economics point of view to deal with ecological and economic systems. Under this circumstance, its sustainable development model has moved forward. Finally, evolution economics is from the interaction of ecosystem and economy system arising from emergence of co-evolutionary point of view[8], further strengthening the system's development, balanced dynamic and adaptive characteristics, i.e., from the evolution economic viewpoint to deal with the economy system and ecosystem, which is more towards sustainable development.

1.1. The resource integration

In recent years, the electric industry has faced limitations on carbon dioxide emissions, fuel consumption, high energy prices, right of way for transmission lines construction, public protests, substation and transmission line maintenance and many others. As a result, the integration of power supply and demand resources attracts attention. With effective integration of supply and demand of power resources, developing demand side resources to substitute for supply resources could improve the overall financial efficiency of power resources, relieve supply-side shortages, and satisfy increasingly stringent environmental requirements. Integration hence provides new solutions to the power industry.

In fact, the integration of power resources is not a new proposal. As early as the era of planned economy under regulation, public utilities in advanced countries have developed the so-called "serial demand-supply planning" model to carry out long-term resource allocation and planning according to electricity demand forecasts. In the 1970s, the public power sector started to promote integrated resource planning. They evaluate and select candidate resources by comparing the costs and benefits of both demand-side and supply-side resources, in order to reduce power supply costs and improve reliability, taking into account the interests of the electricity industry, users, and society. During this period, it was called "the parallel demand-supply planning" model. In the 1980s, with the environmental concerns of regulatory agencies and environmental organizations, some countries such as the United States gradually incorporated renewable energy, distributed energy resources, and demand side management into the power integrated resources planning program, through imposing legislative or other regulatory requirements on the electricity industry. In this period, the resource integration of power supply and demand was first done at the regional level, which can request the support of back-up system in case of shortage. Therefore, the dependence on the overall electricity system can be reduced, thereby effectively alleviating the congestion problems of the power grid and transmission line and line-loss problems, thus greatly improving the efficiency of power resources. In this period it was known as the "parallel model of regional resource integration".

Since the beginning of 2000, as the result of rapid development of information technology, automation technology and communication technology, the new generation of electric power system infrastructure – smart grid (or micro-grid) – has been successively developed and soon raised a lot of discussion. The future development framework of the smart grid is expected to integrate renewable energy, energy storage systems, distributed power, and demand side resources more effectively, and it might become an important network platform for the integration of regional supply-side and demand-side resources. In the future, it is more likely to evolve into a "smart grid oriented IRP" and grow into a new business model of power supply and demand resource integration. Based on this "long-term power supply and demand resource integration" point of view, the study makes an attempt to propose the role of smart grid under the regional integration of power resources and to give insights into the "smart grid oriented IRP" development process. In particular, in the face of increasingly attention towards environmental protection in the future, the "smart grid oriented IRP" would lay the foundation for the development of "industry-resources-environment" symbiosis model of "power oriented eco-industrial park".

1.2. Sustainability index

Sustainable development indicators can be built from the diversified feedback viewpoint of DPSR (driving force, pressure, state and response), including: (1) energy indicators such as EXERGY and EMERGY, which emphasize the quality of energy, in addition to disclosing the quantity. EXERGY distinguishes "available energy", which can perform work, from "unavailable energy", which cannot perform work due to dissipation, in order to define the quality of the energy. On the other hand, EMERGY uses solar energy as a reference unit to define the scale and quality of energy, as it transforms from the source (i.e. solar energy) to low density energy such as the wind, and then to high density energy such as electricity on the same base. (2)

Environmental indicators, covering the consideration of ecological footprint and carrying capacity under resource and environmental constraints, as well as the consideration of carbon footprints; (3) Flexible indicators, which denote the vulnerability, robustness and stability of ecological sensitivity and resilience; and (4) Integrated index, which integrates the energy, economic and environmental (3E) sustainability index. The first class, second class and the fourth class are deterministic or random indexes, while the third class is an adaptive index.

1.3. Cybernetic

Relativistic theory, evolutionary theory and Cybernetics are three of the 20th century's great inventions. Cybernetics is widely used in engineering, economics, social and ecological control, and its theoretical foundation consists of the deterministic optimal control model, stochastic random optimal control model with random interference and measurement error, and the deterministic/stochastic adaptive control model considering the structural adjustment of the system. A more generalized scope could extend to forecasting, planning and dynamic simulation. Forecasting and planning are both feed-forward controls. Forecasting needs state variables and state functions to do estimation, while planning needs an objective function to find the optimum solution, in addition to considering the constraints of the state variables and state functions. Simulation covers the feed-forward and feedback control (i.e. ex-ante and ex-post). Feedback control is to adjust the control variables according to the feedback messages produced by measurement variables in order to achieve the optimum objective. Decision making requires forecasts, planning and simulation, coupling with comprehensive evaluation.

Generally speaking, this paper focuses on the energy flow of regional integration of energy resources under sustainable power development, by the way of adaptive control for supporting dynamic decision. The detailed research processes include to: (1) design decision-making scenarios for dynamic planning of sustainable power development, (2) establish indicators for sustainable power development, (3) establish an evaluation mechanism for sustainable power development, (4) establish a dynamic simulation model for sustainable power development, (5) carry out dynamic simulations and forecasts for sustainable power development, (6) integrate the 3E multi-objective planning for sustainable power development, (7) carry out dynamic system simulation for sustainable power development, and (8) develop dynamic decision-making in a co-opetition game under multi-agent network for sustainable power development.

2. Methodology

The "adaptive control theory" is applied to this research, taking into account the data processing requirement under the complexity, uncertainty and sustainability of ecological-economy, circular-economy and evolutionary-economy theory. It also integrates information processing capability of adaptive forecasting, planning, control, simulation and decision making and then makes practical application to dynamic IRP systems centered on electricity.

2.1. Theoretical basis

2.1.1. Adaptive control[16]

(1) State function

a. Continuous type

$$\dot{X} = f\left[X(\theta,t),U(t),t\right] = A(\theta,t)X(t) + B(\theta,t)U(t) + W(t)$$

b. Discrete type

$$X(K+1) = \phi(\theta,K)X(K) + H(\theta,K)U(K) + W(K)$$

(2) Control function

a. Continuous type

$$U(t) = -K(\theta,t)X(t)$$

b. Discrete Type

$$U(k) = -L(\theta,k)X(k)$$

(3) Measurement function

a. Continuous type

$$Y(t) = C(\theta,t)X(t) + V(t)$$

b. Discrete type

$$Y(k) = C(\theta,k)X(k) + V(k)$$

(4) Objective function

a. Continuous type

$$J = f\left[X(t),U(t),t\right] = \phi\left[X(t_f),t_f\right] + \int_{t_0}^{t_f} F\left[X(t),U(t),t\right]dt$$

$$= X^T(t_f)Q_0X(t_f) + \int_{t_0}^{t_f}\left[X(t)Q_1X(t) + U^TQ_2U(t)\right]dt$$

b. Discrete type

$$J = E\left\{X^T(\ell)Q_0(\ell)X(\ell) + \sum_{k=0}^{\ell-1}\left[X^T(K)Q_1(K)X(K) + U^T(K)Q_2(K)U(K)\right]\right\}$$

(5) Note

a. θ is unknown parameter vector of system.

b. W(k)，U(k) are random series.

c. The purpose is to choose control function U to optimize performance J, as in shown Fig 1.

2.1.2. Adaptive Evaluation

(1) Basic Concept

Use value = direct use value + indirect use value + option value

(2) Model

a. Deterministic model

-> The formula for net present value is:

$$\mathrm{NPV} = \frac{\sum_{0}^{n} B_i - \sum_{0}^{n} C_i}{(1+r)^i}$$

b. Stochastic model

-> The formula for net present value is :

$$\mathrm{NPV} = \frac{\sum_{0}^{n} P_{ib} B_i - \sum_{0}^{n} P_{ic} C_i}{(1+r_i)^i}$$

P_{ib}、P_{ic} may be the objective, subjective or Monte Carlo simulation probability.

c. Real option method

-> Referring to the Black-Scholes method[18], the formulas are as follows:

$$\mathrm{C} = SN(d_1) - X\mathrm{e}^{-rT} N(d_2)$$

$$d_1 = \frac{\mathrm{e}_n\left(S/X\right) + rT}{\sigma\sqrt{T}} + \frac{\sigma\sqrt{T}}{2}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

T: The time to maturity

C: Call option value

S: The price of the underlying assets

X: The exercise price

r: The risk-free rate

N(d1)：The cumulative normal probability of unit normal variable d1

N(d2)：The cumulative normal probability of unit normal variable d2

$\sigma\sqrt{T}$ ：The standard error of sampling time T

$\frac{rt}{\sigma\sqrt{T}}$ ：The biased Z value of expected underlying assets value under the effect of risk-free rate

$\frac{\ell_n\left(S/X\right)}{\sigma\sqrt{T}}$ ：Z value of exercise price in normal distribution

In the power industry, the five key factors affecting the value of power assets option are: (1) the price of the underlying asset: the expected electricity price (2) the exercise price: the expected variable cost of production, e.g. fuel cost (3) the time to maturity: an hour in the life cycle of power assets (4) uncertainty: price volatility (variable price and cost) and (5) risk-free rate: the interest rate of treasury bills.

2.2 Research framework

The ecologically governed adaptive management system is based on the control theory of cybernetics and control theory of engineering systems, in which adaptive control is different from optimal control. The latter uses a specific objective to determine the control function, and the control rules are determined beforehand. On the other hand, the adaptive control changes its control rules simultaneously with the change of environment. Therefore, adaptive control could be applied to manage complicated and dynamic ecological systems. However, evolving from the optimum control into adaptive control has to go through the following processes: (1) the optimal estimation: to estimate the system state of interference by the measurement output of random interference; (2) the random optimal control: to determine the control function by the system state of random interference under a specific objective; (3) the dynamic system identification: to identify the system characteristics (equation) by system's dynamic input and output; and (4) the adaptive control: to adjust control rules using a variety of direct or indirect identifications on system dynamic characteristics, in order to achieve optimal control. The progression from the "deterministic" control to "random adaptive" control lead the system to move from "disorder" toward "orderly" direction, which is in favor of system management. Furthermore, applying 'chaos control' following the development of intelligent control e.g. artificial neural network control, genetic algorithms control, and fuzzy logic control etc., i.e. doing periodic synchronization and chaotic synchronization using perturbation simulation, to disordered random system is currently a more advanced control technology development.

The basic core philosophy of this research is the "adaptive control theory", step by step from optimum control, random optimal control to random adaptive control. It is based on ecological economics, circular economics and evolutionary economics to deal with the systematic, complex, random, interactive, dynamic and sustainable development system subject to constraints with nonlinear, positive and negative, feed-forward and feedback control characteristics. As for the methodology, it integrates the forecasting, planning, control, simulation and decision making processes from the controllability and observability of feed-forward and feedback control under adaptive self-organizational capability. It is then applied to the power industry, serving as the core of the regional integration of dynamic power operating systems (see Figure 2). The adaptive evolution starts from the traditional power supply and demand, the system with regional IRP, the smart grid oriented IRP, the regional symbiosis Eco-industrial Park(EIP), and finally turns into the sustainable regional resource integration model.

3. Design and planning of adaptive dynamic decision models

3.1. Overall integrated resources planning (IRP)

In the planned economy under regulation, demand-side management (DSM) is considered as negative power demand and thus could be treated as a kind of resource. Therefore, it can be integrated with supply-side resources to attain the optimal integration planning of supply and demand resources. DSM measures mainly involve the reduction of electricity demand, power efficiency improvement and load transfer to reduce capacity requirements. The purposes of DSM are to achieve the optimal planning of power resources, including the overall optimal planning of power system as well as the regional optimal planning, and to reduce the environmental loading. The core business model of IRP is optimal control, including feed-forward control of planning, real time control of execution and feedback control of management.

The main supply-side resources are large, centralized power generation units, including nuclear, fossil, and hydropower. In a market economy, the market pricing mechanism replaces the overall planning of these resources, and it introduces market risk factors. In this case, the resource integration planning of power industry would focus on bringing the market risk into the strategic resource integration planning. The core business model would be random optimal control.

In the smart economy following ICT technological innovation, the smart grid becomes the center of resource integration. The smart grid not only integrates the whole system, from upstream supply-side resources to downstream demand-side resources, but also regionally integrates the centralized generation, decentralized generation and renewable energy resources, including the standby resources of energy storage systems. The core business model under this situation is intelligent control, as shown in Figure 3.

In the ecological economy, the scope of regional integration goes beyond the boundaries of electrical industry and extends to other industries. On the principles of 3R, i.e., resource minimization, re-use and recycle, it will incorporate the material flow and energy flow of resources and form regional ecological industrial parks or ecological communities. Its core business model would be random adaptive control. The resource integration model in ecological economy could be summarized as follows:

(1) “Power supply and demand” resource integration

The scope of this model covers the overall power system. Under this model, the traditional, serial planning model turns into a ‘parallel’ overall resource planning model. That is, for the power supply to meet electricity demand it must consider the resource constraints and treats demand side management as a resource, namely “a negative power”, in order to integrate both the supply side and demand side.

(2) “Power supply and demand” regional integration

Regional oriented IRP is the main planning direction of this model. Under this model, system-level power resource integration planning evolves into ‘regional’ oriented power resources, and links to the system level power supply and demand resources to become a ‘composite’ planning model.

(3) “Smart & symbiosis” regional IRP

Based on regional IRP, it regards the micro grid as the core to effectively integrate distributed generation power, renewable energy, energy storage system and the demand side management under regional IRP model. It goes towards power-industry-oriented eco-industrial park under cross-enterprise, cross-industry ‘industrial symbiosis’ resource integration, including the reduction, reuse and recycling of material and energy.

(4) “Power oriented sustainable” IRP

Based on the symbiosis regional IRP, it takes into consideration natural resources, environment and land suitability (development potential vs. limitation) to incorporate regional and interregional power resources and the natural resources into resource integration planning and territorial planning.

3.2. Smart grid oriented IRP

The purpose of the smart grid is to integrate (1) advanced electronic automatic technology such as intelligent electronic devices (IED), (2) new communication with protocol system such as broadband Ethernet, IEC61850, etc., and (3) advanced information system capability such as online information search and storage by adopting the digital technology. It needs to restructure the power grid, including (1) the new system framework such as power stations, feeder and grid automation, e.g., micro grid, (2) new operational capability such as self-monitoring, self-control, self-prevention, self-diagnosis, self-adjustment, self-protection, self-recovery and self-healing, and (3) the capability of the optimal assets management for new equipment and devices.

Then the smart grid can apply to the new power system effectively and adaptively to integrate (1) the distributed energy resources such as local modularized units, renewable energy and new energy, (2) energy management such as energy management system (EMS) and DSM, (3) the power trading such as real time, day-ahead, auxiliary services and demand response(DR) trading so as to: (a) improve the safety and quality of the grid, (b) improve the energy efficiency, resources integration and reduce the cost, (c) decrease the pollution, and CO2 emission, (d) promote the power trading, and (e) upgrade the quality of customer services. As a result, the smart grid can become the core of regional integrating resources. By adopting its technological characteristics, it can effectively integrate renewable, distributed energy resources, storage, DSM and demand response to be the optimal symbiosis application model of the resources, as shown in Fig. 3.

3.3. Industrial symbiosis resource integration planning

As an extension of smart grid oriented regional IRP, “Regional power oriented Eco-industrial Park(EIP)” has the characteristics of the electrical industry as the core according to the circular economy and ecological economy principle, i.e., (1) 4R: Reduce, Reuse, Recycle and Remanufacture; (2) 3D: Dematerialization, Decarbonization and Detoxification; (3) 3G: Green Procurement, Green Production and Green Consumption (4) 4E: Eco-Design, Eco-Process, Eco-Product and Eco-Service; and innovation principles, i.e., 3C: Corporate Innovation, Customer Innovation and Competitive Innovation. It would link with other related symbiosis industry (for example, high-tech industry, energy industry, etc.) to establish a new cleaner production, consumption for sustainable green management under the industrial symbiosis organization.

3.3.1. The framework

“Regional power oriented eco-industrial park” combines the push driving force by material flow (such as raw materials, water, products, by-products, waste, etc.), energy flow (such as heat, chemical energy, power, etc.) and information flows (such as information, knowledge, intellectual property; technology, product and exergy) with the pull driving force by commercial flow (such as agreements, contracts, business, etc.) and money flow (such as cost & benefit,, price and value, etc.), under incentives (such as policy, regulatory, institution, infrastructure, etc.), towards integrating producers, consumers and media (or integrator) into a positive bi-directional loop between business “links” or “network” symbiosis. It forms an industry portfolio of “resource integration” and “shared resources”, allowing the production of by-products or waste by some enterprise to become raw materials or energy for the production of other enterprises, hence achieving sustainable development purposes of “material recycling”, “energy multi-level usage” and “waste minimization” , as shown in Fig 4.

3.3.2. Principle

The basic development principles of the circular regional power oriented eco-industrial park network system are:

(1) Ecological philosophy: composite philosophy of conservation and preservation；

(2) Ecological economic criteria:

(A) Elementary capital portfolio criteria: artificial capital and natural capital is incompletely or not substitutable by each other,

(B) Input criteria: (a) renewable resources: development rate within the regeneration capacity limit, (b) non-renewable resources: depletion rate within the alternative resource capacity range, (c) output criteria: waste disposal in the area within the carrying capacity limitations of the environment;

(3) Ecological indicator:

(A) Conservation: (a) ecosystem health indicator for stability (b) ecological sustainability indicator for development,

(B) Preservation: (a) biodiversity indicator including genes, species and ecosystems for robustness, (b) the ecological integrity indicator maintaining the overall structure & function and resilience;

(4) Ecological policy:

(A) prevention principle

(B) minimum security standards

(C) threshold specification; and

(5) Ecological governance: (A) watershed management (B) adaptive management.

The citizens community of the regional power oriented eco-industrial park network is the “civil society” that includes shareholders, employees, suppliers, customers, citizens, community and the central/local government, non-governmental organizations, community organizations and other stakeholders of the eco-social network. Each stakeholder is a node of the ecological network. In addition to being a personal decision maker, the stakeholder also serves as an agent (of producers, consumers or media) for public policy decision making, and through a two-way interaction to become “multiple agents”, including national “rights” agents, market “contract” agents, “management” system agents, community “relationship” agents and professional “knowledge” agents as a public policy decision-making mechanism.

The exchange platform of circular resources is designed to provide producers, consumers or media a “self-organizing” symbiosis platform for resource sharing, complementation, integration, and exchanges through interaction among each other. The platform includes: (1) symbiosis (+,+) (2) competitive (-,-), (3) parasitic (+,-), (4) damage (-,0) (0,-), (5) commensalisms (+, 0) (0, +) (6) accompany (0,0) and other co-opetition relationship, turning into an positive “symbiosis” relationship (+,+) of “ecological” social network”, in order to construct a circular economy of ecological resource flow, moving towards a world of sustainable development with 3E (energy, economic and environment), three livings (production, life and ecology) and three sustainability (sustainable economy, society and ecology).

In the value network of circular regional power oriented eco-industrial parks, each company will strive towards the double complementary role of both product company and resources recycling company, i.e., having both producers (product manufacturing, recycling) and consumers (product use, recycle) symbiotic functions.

Under the emission reduction pressure of “carbon footprint” (carbon emission intensity) and “ecological footprint” (the ecological area required for carbon sink), the power company will proactively play a key role in the ecological network (as mediators: motivator, integrator, such as energy service companies), and plans to become the core enterprise of the “power oriented eco-industrial parks network”. Such motivation is compatible with the corporate interests and social responsibility, originating from the idea of “ecological ethics”, including eco-value, eco-culture and eco-oriented strategic “anticipatory” actions. Thus it will change the future carbon dioxide reduction scenario, moving towards a future of sustainable development with electricity-based cross-boundary “ecological governance”.

3.3.3. Prospects

Under the prospective vision, the “power oriented eco-industrial park” mainly takes into account environment, economy and energy (3E) as the core development of a new model for the power industry, in order to establish a sustainable power infrastructure of the EIP. Such prospects include a power resource integration center based on micro grid and automatic meter infrastructure (AMI), covering supply-side resources of renewable energy (e.g., photovoltaic, wind, and their integration with fuel cell, biomass, etc.), distributed power (e.g., gas turbine with carbon capture and storage (CCS), gasification fuel cell, etc.), energy storage system (e.g., compressed air energy storage systems, etc.), demand side resources (e.g., high efficiency, energy saving, load management, demand response and energy services, etc.) and promote real-time, grade, green, and regional electricity pricing.

Secondly, EIP companies, linked in material flow, energy flow, information flow, commerce flow and money flow of the “circular ecological economy” symbiosis network, are appropriately integrated into the power resource integration infrastructure. It covers new businesses derived from power industry including resources company (Jatropha oil products with “biomass/drug/carbon sinks”, high cellulose biomass crop, aquaculture), chemical company (recycling SO_X, NO_X, CO_2 and other emissions of power plant, producing nitric acid, sulfuric acid, soda and other chemical products), cosmetics company (using micro algae to absorb carbon and use for mask cosmetics), resource recovery company (recycling wastes and household appliances), seawater desalination company (using wind power for desalination of seawater), gypsum company (recycling coal ash from power plant to make gypsum), digital home services company (integration of power information, AMI and broadband services to provide digital home information service), energy companies (energy supply and energy consultants, energy risk management and carbon asset management services). Industrial symbiosis enterprises including PV companies, high-tech industries (electronic, communications, biotechnology, electrical, optical, etc.), wind energy companies, energy intensive industries (pulp and paper, chemical, textile, cement, etc.), cogeneration company, green energy service companies (demand response and energy services), green energy electrical company (green refrigerator, inverter air conditioners, etc.), green home appliance company (lighting, refrigerator, air-conditioning, etc.), green luminary company (LED and its integration with photovoltaic, etc.), and eco-construction company (green building, smart building, BIPV, etc.). Through raw materials, waste, energy and information exchange, these symbiosis companies mutually coexist to shape a complementary network resource exchange platform, and on the whole, to include eco-industrial, ecological services, ecological agriculture, forestry, fisheries, and eco-community network.

Finally, through natural ecological design consultants, new business for corporate social responsibility (CSR) by 3E venture capital companies, ecology program project financing by investment banks, green electric car company of PHEV and eco-tourism company for eco-tourism route planning, the sustainable ecological management model would be formed to provide overall ecological investment and ecological services in EIP. The more detailed scheme of industrial park resources symbiosis is shown in Figure 4.

3.4. Multi-agent institutional system design

Along with the changing environment, including technological developments, market advances, ecology evolution and value changes, it promotes the social demand of public property covering internal and external property rights, and forms the basis for a multi-agent system design. The information of actual market trading and virtual market modeling, in addition to feedback to the institutional design, will further provide government and enterprise agents for creating private property rights to support business decisions. Through the systematic evaluation of the option and the valuation of property, the assessment process between the government and enterprises will create a multi-agent decision mechanism to promote innovative change of business model towards ecological oriented adaptive management, in order to improve social behavior accordingly. The model is shown in Figure 5.

3.5. Real option evaluation

Traditional investment plans for power generation, transmission and distribution use NPV analysis for cost-benefit assessment. Basically it is based on the prevailing hypothesis of benefit, cost, and the discount rate to reflect to the discounted cash flow (DCF), which is called the determined model. However, with the progress of time for the project, the cost-benefit of the actual situation is obviously quite different than originally expected, considering the market uncertainty factors including market fluctuation such as electricity demand, fuel prices, electricity price and carbon price, etc., power technological development, such as generation, transmission and distribution BAT (best available technology) and environmental BACT (best available controlled technology) as well as policy and institutional changes such as non-nuclear policy, renewable energy development, low energy tax law, greenhouse gas reduction law, cogeneration promotion law, energy management law, electricity law, etc..

Meanwhile, under the reality of new market and business information, it would be possible to change a decision on generation, transmission and distribution, operation, including flexible changes from planning, design, construction, operation, maintenance, to services (covering project size, cancellation, or delay, etc.). If these uncertainties and changing factors could not be effectively incorporated into the scenario planning and investment portfolio in advance to develop a strategy and simulated response, it would result in decision making that is difficult to adapt to the changing environment and meet cost effectiveness. Examples include the huge impact of the fourth nuclear power plant, the purchasing dispute of cogeneration and IPP, arising from incomplete contract and its derived hold-up or stranded contracts in Taiwan. This is probably the consequence of not adequately including the required scenario into the original portfolio planning and retaining sufficient operating flexibility in advance.

Real options can be considered as the future invested resources of the enterprise, including appropriate investment in products, services or projects, covering its permission right, feasibility assessment, reserve capacity margin and other tangible or intangible assets. It is a kind of opportunity right to decide whether to continue investment in the future or make other changes. Based on new acquired information in the future, it has the right to make adjustments to decisions made on the ongoing project, including the option to abandon; defer deployment; expand or contract; expand or shorten; scope up or scope down; and switching, compound, and rainbow options. The effect is as the same as the financial option comes at a premium, having the right at a specific point in time in accordance with the contract of the strike, to buy or sell a certain number of subject-matter of the right (but not the obligation), i.e., having a finite investment cost and getting the opportunity to create unlimited benefits in the future. This is different from the NPV, as it regards various action plans as mutually exclusive options under possible future scenarios. It adds the various alternatives into the investment portfolio, according to a cost-benefit assessment of dynamic market information, forecast information and real option assessment (that is an option value), and makes a decision on the optimal point of execution, thus affecting exercise price (cost) and the underlying asset price (benefit). Therefore, it is a dynamic and cost-benefit analysis under the dynamic decision-making.

4. Empirical analysis - optimal portfolio of regional industrial symbiosis dynamic adaptability.

4.1. Establishment of energy system diagram

This report constructs the tentative design framework of the “regional sustainable electricity system”. In addition to the basis of the Odum system ecological principle [19] and environment and policy planning, it also originates from a power oriented ecological economics-related design concept. From the vision plan of national sustainable power planning, combination of circular power supply and demand, and portfolio of power resources, the design concepts of regional IRP will be included with a symbiotic power network. Furthermore, referring to power oriented ecological economy related indicator and adaptive control principles, it proposes a system dynamic mechanism of sustainable power to facilitate future policy simulation. Its initial concept design is summarized as follows:

i. “Smart grid” integrates the supply side of power (concentrated generation including gas-fired, oil-fired, coal-fired and nuclear energy; decentralized generation including solar, wind, hydro, biomass, etc.) and the demand-side negative generation (DSM resources and carbon assets management) integrated as a “power producer” and electricity production of the power system.

ii. The “production” activity of industry (agriculture, industry, services sector) and the “life” activities of the community would constitute the “consumer” and consumer activities of an overall electricity energy system.

iii. The “information center” integrates “management center” (incubation center, energy center and service center, etc.) and NGOs (industry unions, consumer associations and environmental groups, etc.), and through the supply mechanism (including science and technology, management and ecological mechanisms) and demand mechanism (including the market, economic and social mechanisms) as a multi-agent system (various center such as incubation, energy and services center and trade unions, associations, communities with other types of non-governmental organizations NGOs for citizen participation mechanism) and the governance mechanism design (environmental management, environmental accounting, life cycle assessment, ecological design, clean production, green consumer, adaptive management, ecological engineering methods, ecological planning, etc.). It also has information interaction and added value, changing from the “low energy density potential” of "electric energy producer" to "high energy density potential" of "power consumers".

iv. Demand side resources and carbon asset, via energy management and carbon asset management, can form a negative power (a type of resource) of supply-side power "parallel planning".

v. Waste (including SO_X, NO_X and CO_2), through resource recycling "feedback", can become raw materials of other industries (e.g., the plaster made from ash, carbonic acid made from CO_2, nitric acid made from NO_X and SO_X made into sulfuric acid, and renewable energy power offers electricity for seawater desalination, etc.) and community life products (such as CO_2 absorption by algae to produce mask, creams, other cosmetic products and Q10 nutrition product, and biomass from Jatropha oil, health, medicine, and carbon sequestration multi-purpose application, etc.).

vi. Land, water, and trees as a source can provide ecological services for a regional system, and can also act as carbon sinks and heat sink to constitute internal water cycle, the nitrogen cycle and the carbon cycle of the system.

vii. Electricity trading (market) and dispatch of power are closely linked to integrate the supply and demand of electricity to form the core of the system.

viii. Through the external market, various industries make production and trading of a variety of products and services. A variety of communities make transactions for various necessities. Related policy and control system regulates the production activities of various industries.

ix. Natural resources (including renewable energy, geology, topography, hydrology, soil, biology, humanities and land), is the source and sink of the environmental system. Through the carrying capacity as output limitation criteria and development ratio of renewable resource with depletion rate of the non-renewable resource as input limitation criteria, and referring to exergy indicator reflecting ecological physical characteristics of quality, or other indicators such as the ecological footprint, carbon footprint and conform to the ecological sustainability, healthiness, integrity and diversity indicators, it is necessary to regulate the suitability of power system development under development and limitation.

x. Waste heat (entropy) generated by various energy flow and material flow are discharged to the environment outside the system.

xi. For future directions, selecting suitable control variables and state variables to establish a system of dynamic simulation model is needed for policy simulation and detailed design planning.

xii. The system is shown in Figure 6.

4.2. Establishment of the system dynamic map

The system dynamic application for energy and power planning is basically classified into several underlying application areas to support decision making: (1) the power sustainable development: optimization of “social” welfare with 3E system dynamics (2) long-term power supply and demand planning: optimum “industrial” planning with consideration of “long- term” power resources (3) short-term power dispatch: to consider “short-term” power resources for industrial optimum operation (4) short-term power trading: to consider “short-term” electricity trading for the “market” adaptive equalization (5) electric industry strategic planning: to consider electrical operation for “enterprise” optimum strategy in order to simulate future development scenarios: (a) CO_2 emissions, (b) energy tax or carbon tax, (c) power technology development, (d) renewable energy development, and (e) fuel price volatility.

The power supply and demand system as a core subsystem of the whole “sustainable” system is designed to achieve sustainable economic development. It is necessary to further identify their relationship, on the one hand, and the associated interface on sustainable social system for linking, including pain index (e.g., illness, death, unemployment, etc.), happiness index (e.g., health, safety, happiness, etc.), risk index (e.g., disaster, crisis, etc.), interests index (e.g., price), as well as human capital (e.g., population, labor, industry, etc.), artificial capital (e.g., technology, money, etc.), and social capital.

On the other hand, it needs to be linked to “sustainable ecosystems”, covering consideration of the pollution effect of land, water and atmospheric environment of the lithosphere, atmosphere and hydrology on climate, forest, marine and water resources, and the interaction between their carbon emission sources and carbon sinks. In addition, it also considers the biodiversity of the biosphere, ecological footprint, food network and the interaction mechanisms from energy flow and material flow system of bio-energy. Its integrated dynamic framework is shown in Figure 7.

4.3. Preliminary results

A simplified model was applied to the simulation including the portfolio of power resources (renewable, non-renewable, DSM, carbon assets management and smart grid) as the state variable, the indicator (sustainable index and adaptive index) as the measurement variable, the value and risk as the objective, the external uncertainty factors such as market demand and price, policy, and technology development, the internal flexible factors such as the technology choice. The institutional business model decision mechanism for simulation is shown in Figure 8.

The preliminary results of simulation from the case study are summarized as follows:

I. Under the weak sustainability scenario reflected by low sustainability with a low adaptive indicator and low value with high risk objective condition, the carbon reduction of power infrastructure is required through a dynamic resources mix, which includes: (1) adaptively increasing the control capability of smart grid, (2) adaptively decreasing the use of fossil fuel generation resources, (3) adaptively increasing renewable generation resources, (4) adaptively increasing demand-side management (DSM), and (5) adaptively reducing carbon emissions through carbon assets management.

II. Under the moderate sustainability scenario reflected by moderate sustainability with a middle adaptive indicator and middle value with middle risk objective condition, in addition to the aforementioned change of power infrastructure, it will impact economic growth and lead to adaptive change of industrial structure.

III. Under the strong sustainability scenario reflected by high sustainability with a high adaptive indicator and high value with low risk condition, it will result in a significant decrease of economic growth due to land use limitations associated with carrying capacity and ecological footprint.

5. Conclusion and future research

This study adopts the “adaptive control theory” as the major approach that has evolved from optimal control through to stochastic optimal control and then to stochastic adaptive optimal control. Complex, dynamic and feedback characteristics originated from ecological, cyclic and evolutionary economics are incorporated, together with methods of decision processes in which system’s self-organizational capability and feedback effects are taken into account. In the end, the proposed approach is applied to the electric power business-focused operational system with integrated resources, which includes the adaptive evolution of the electric power-based integrated resources, the eco-industrial park and industrial symbiosis-based integrated resources, and the land sustainability-based integrated resources.

This study intends to construct the framework of the dynamic adaptive decision models of integrated resources under sustainable power development. Three objectives can be summarized. First, is to design the dynamic programming decision context considering external and internal factors affected by mitigation and adaptation strategies based on dynamic integrated resources planning. Second, it aims to build the sustainable indicative system, including the adaptive and sustainable 3E indices, and developing risk assessment models for assets under deterministic, stochastic and dynamic scenarios, respectively. Finally, it builds a dynamic multi-agent co-opetition clouding network system for dynamic simulations, which provide the dynamic adaptive optimal decisions and take into account just-in-time, just-in-place and just-in-context scenarios for sustainable development. However, the limitation of the framework needs to be considered with the results of case study, such as the validation and verification of the model, etc.

The future planning of this research will integrate exergy analysis with dynamic simulation , and will be linked to multiple objective planning for power sustainable development, so that it can better meet the practical needs and future power sustainable development. The planning for the future research is summarized as follows:

(1) Methodology: (a) Integration of cybernetics, systems dynamic simulation and multiple objective planning for 3E, (b) Design of multiple-agent gaming dynamic decision-making system.

(2) Scenario design:

(A) External environment: (a) Consideration of various scenario portfolio for the market, including fuel, electricity, and carbon market volume and price, (b) Policy context (3E policy);

(B) Internal environment: (a) Full consideration of technology portfolio context, including regeneration, fossil energy, energy efficiency, CCS, electrification, electrical appliances efficiency, EV, energy storage, distribution energy, DSM and smart grid, (b) Consideration of the operating environment (business model);

(C) Designing the dynamic scenario planning under the real option model, including (a) System IRP, (b) Regional IRP, (c) Smart grid oriented EIP, and (d)

Power oriented sustainable EIP;

(3) Index system: Building the indicator and objective on the reliability and effectiveness basis including (A) sustainable energy index, (B) sustainable environment index, (C) adaptive index, (D) 3E sustainability index, and (E) value and risk index.

BIBLIOGRAPHY

1. Alan Ingham, Jie Ma, Alistair Ulph, Climate change, mitigation and adaptation with uncertainty and learning, Energy Policy 35（2007）5354-5369.
2. Andrew Ford, Simulating the impacts of a strategic fuels reserve in California, Energy Policy 33, 483-498.
3. Andrew Ford, System Dynamics and Electric Power Industry, Syst. Dyn. Rev.13, 57-85, 1997.
4. Ann Van Ackere, Managing reservoir-based hydro-energy plant：building understanding in the buy & sell decisions in a changing environment, Energy Policy 33(2005) 939-947.
5. Annabalette Wils, End-use or extraction efficiency in natural resource utilization : which is better?, Syst. Dyn. Rev.14, 163-188, 1998.
6. Audun Botterud, A Dynamic Simulation Model for Long-term Analysis of the Power Market, Laboratory for Energy and the Environment, Sept. 2001 to Dec. 2002.
7. Christian Rammel, Jeroen C.J.M. van den Bergh, Evolutionary policies for sustainable development: adaptive flexibility and risk minimizing, Ecological Economics 47（2003）121-133.
8. Christian Rammel, Sigrid Stagl, Harald Wilfing, Managing complex adaptive systems─ A co -evolutionary perspective on natural resource management, Ecological Economics 63（2007）9-21.
9. Daniel Baker, Karen Refsgaard, Institutional development and scale matching in disaster response management, Ecological Economics 63（2007）331-343.

10. Derek W. Bunn, Modelling Latent Market Power Across Gas & Electricity Market, Syst. Dyn. Rev, 13, 27 288, 1997.
11. Dimitrovski, A. Ford，Compressive Long Term Modelling of The Dynamics of Investment & Growth in Electric Power Systems, 2004 EPNES WORKSHOP, MAYAGUEZ, PUERTO RICO, JULY 12-14, 2004.
12. Fernando Olsina, Long-Term Dynamics of Liberalized Electricity Marke,t National University San Juan, Dortored Thesis, 2005.
13. J.J. Ding, Modelling of a Renewable Energy Supply System, Australasian Environment Engineering Conference, 23 May 2000.
14. Klaus Vogstad, Counterproductive environmental policies：Long term versus short term substitution effects of gas in a liberalized electricity market, Norwegian University of Science & Technology, klausv@stud.ntnu.no, 2004.
15. Klaus-ole Vogstad, A System Dynamics analysis of the Nordic electricity market：The transition from fossil fueled toward a renewable supply within a liberalized electricity market, Norwegian University of Science & Technology, Doctored Thesis, 2004.
16. Petros Loannou etc., Adaptive Control Tutorial, SIAM , 2006
17. Levent Yilmaz & Tuncer, Oren, Agent-directed Simulation and Systems Engineering,Wiley,2009
18. Tom Copeland etc., Real Options, Thomson, 2003
19. H.T Odum, System Ecology, John Wiley, 1983
20. Joel B Smith etc., Climate Change Adaptive Capacity and Development, Imperial College Press, 2003

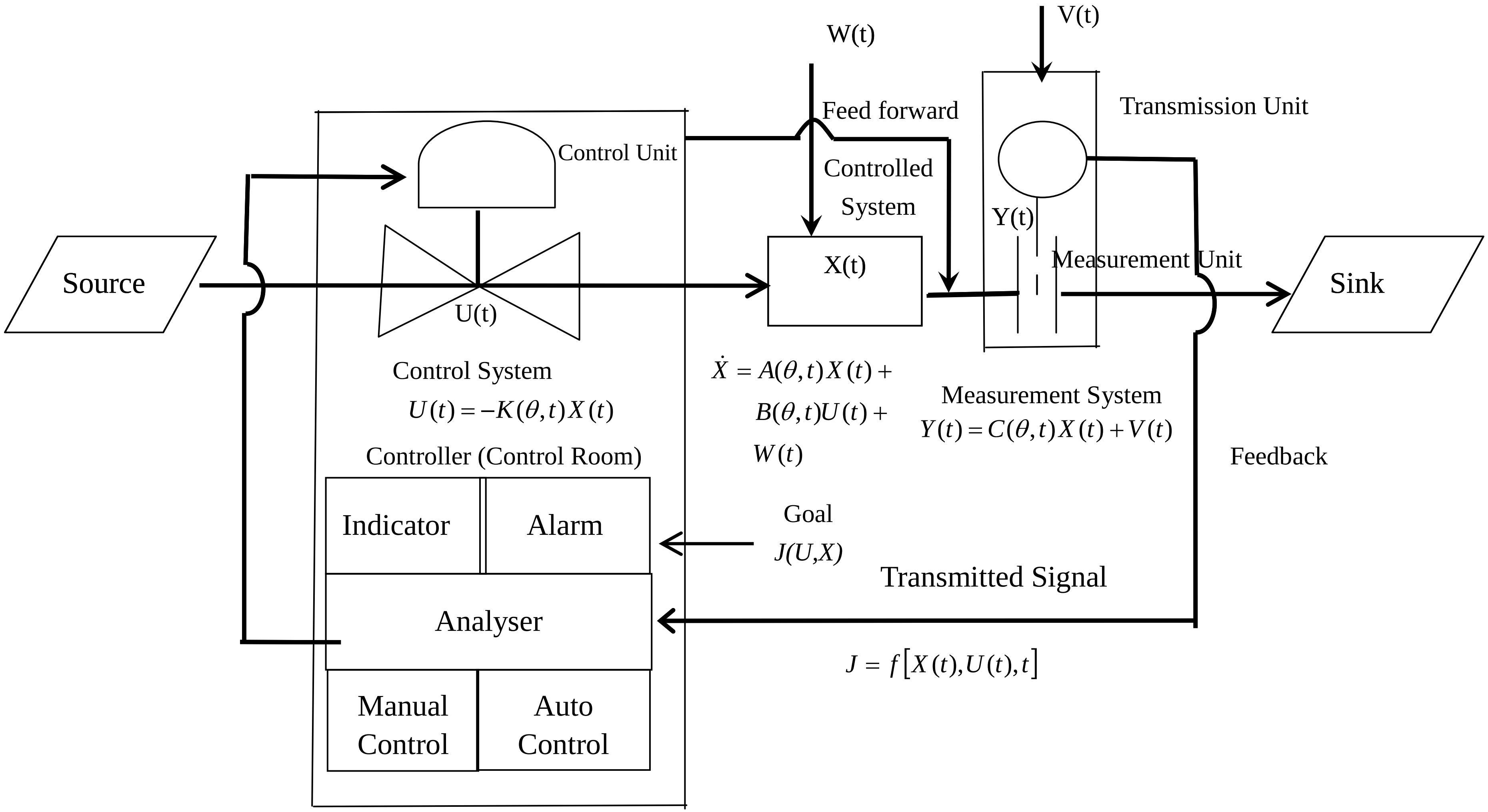


Fig 1： Adaptive Control Flow Chart

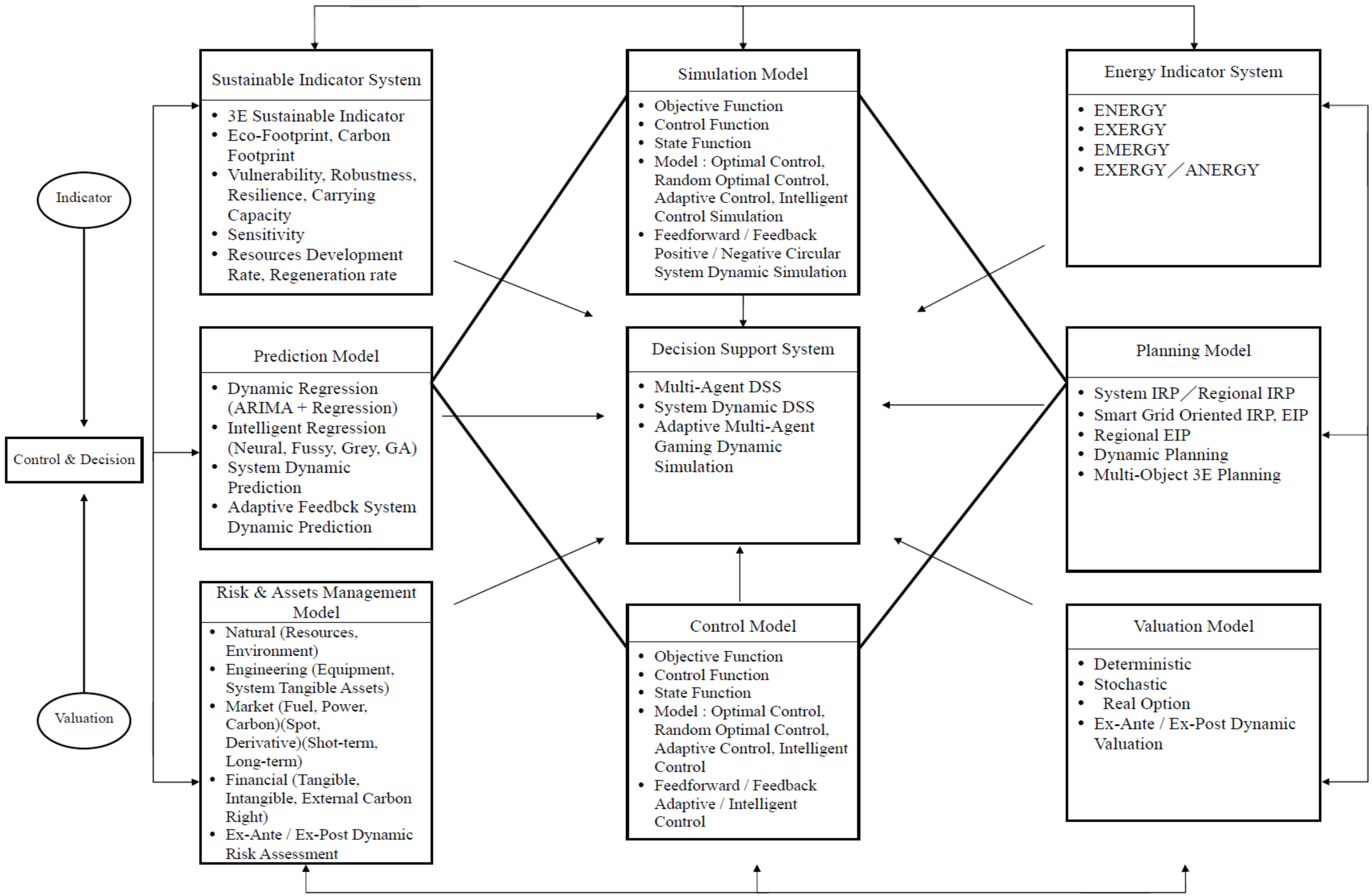


Fig 2：The Concept Design for Building the Dynamic Adaptive Decision Framework of Integrated Resources under Sustainable Power Development

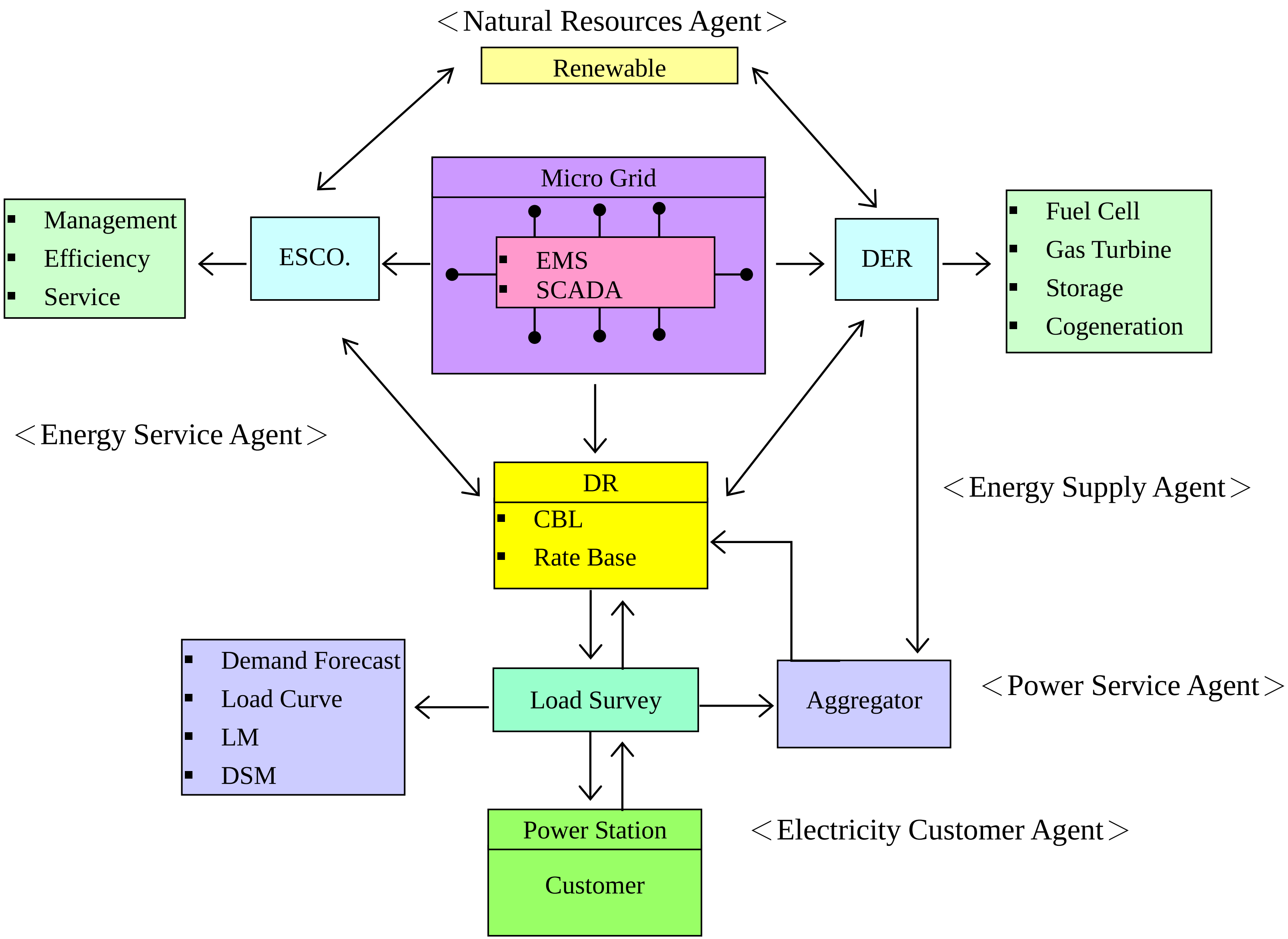


Fig 3：The Framework of Smart Grid Oriented Regional Integrated Planning (RIRP)

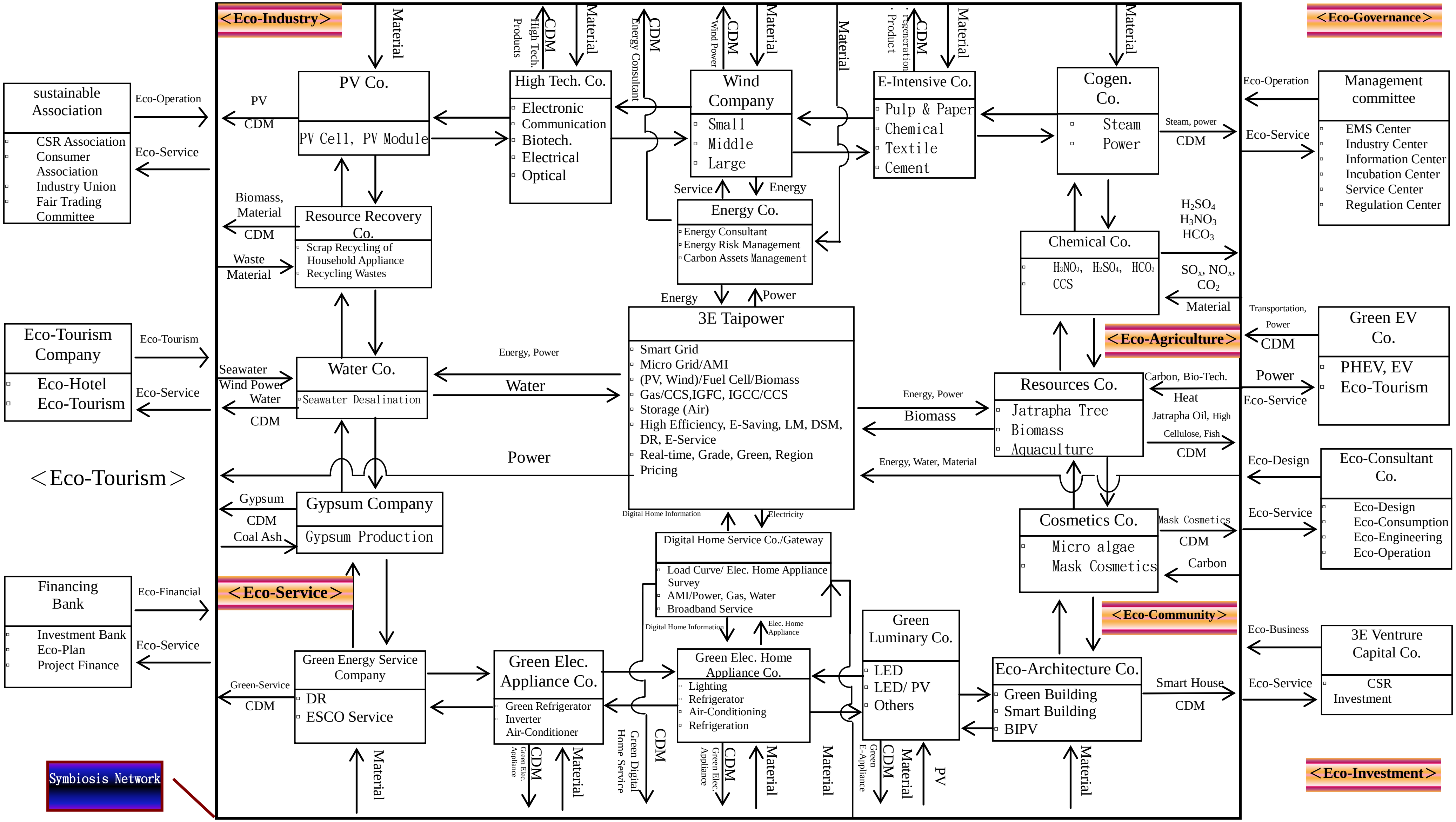


Fig 4 Power Oriented Eco-Industry Park (EIP) Symbiosis Framework

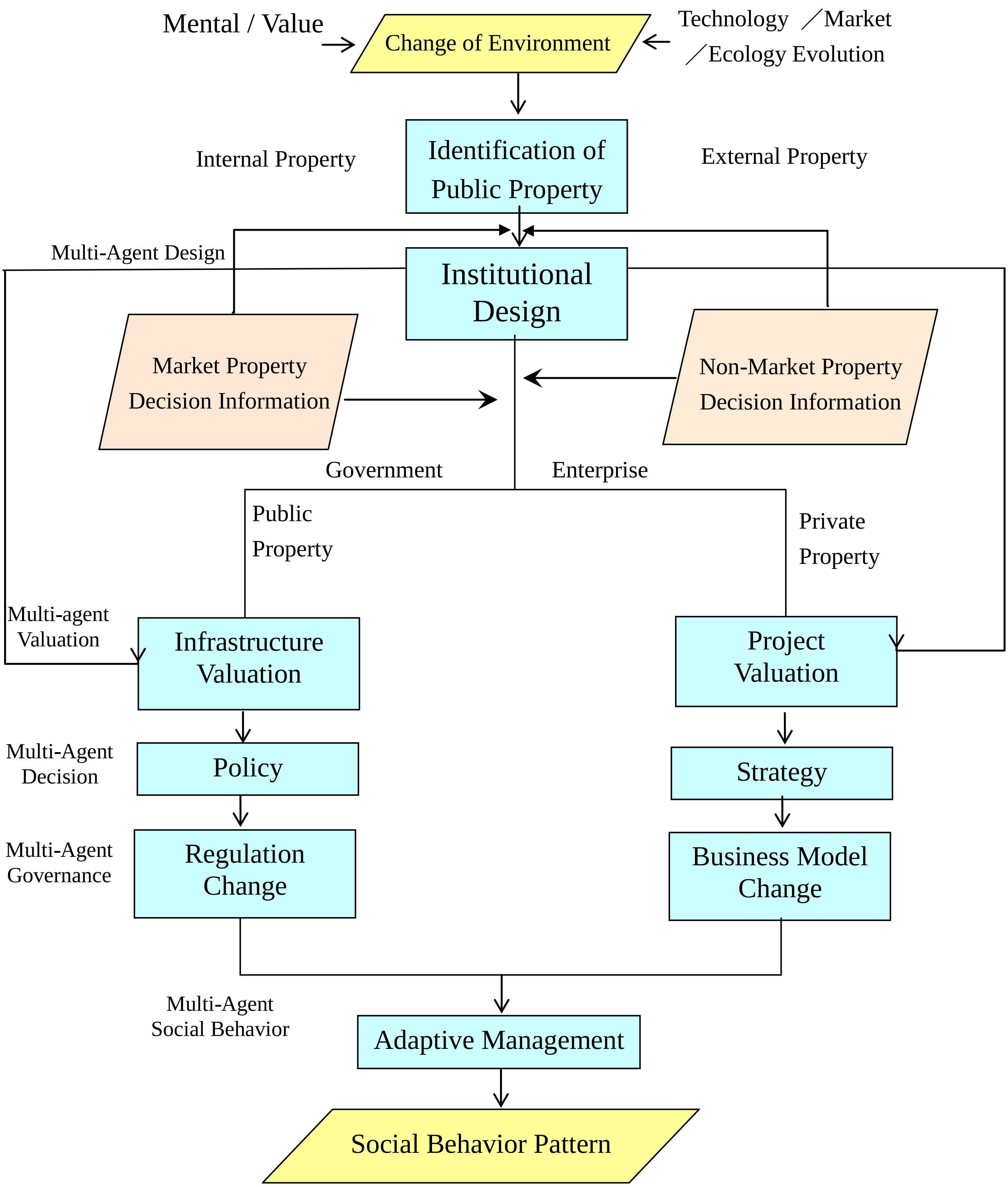


Fig 5：Property, Institutional Change and Decision

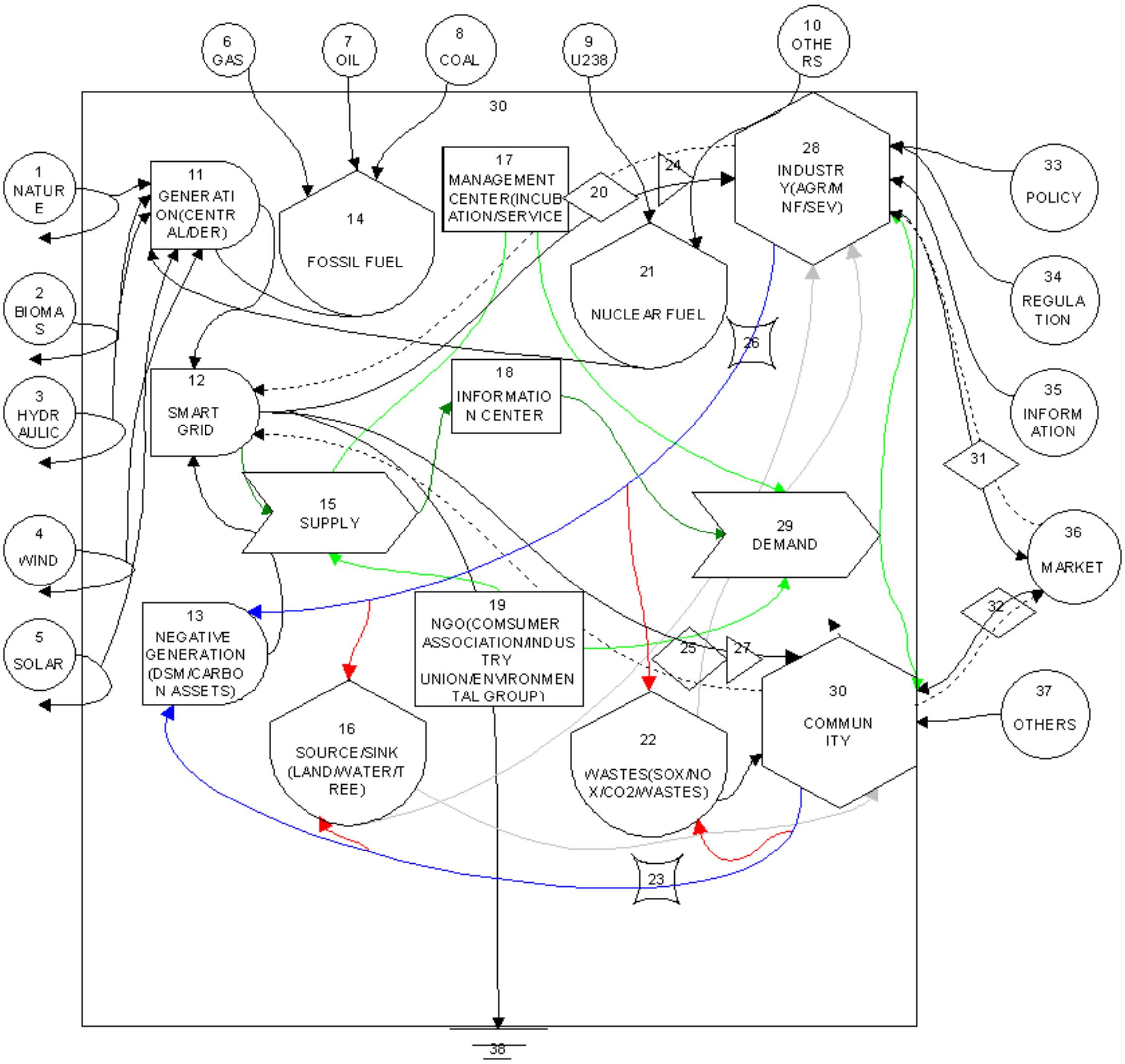


Fig 6：The Design Map of Regional Sustainable System

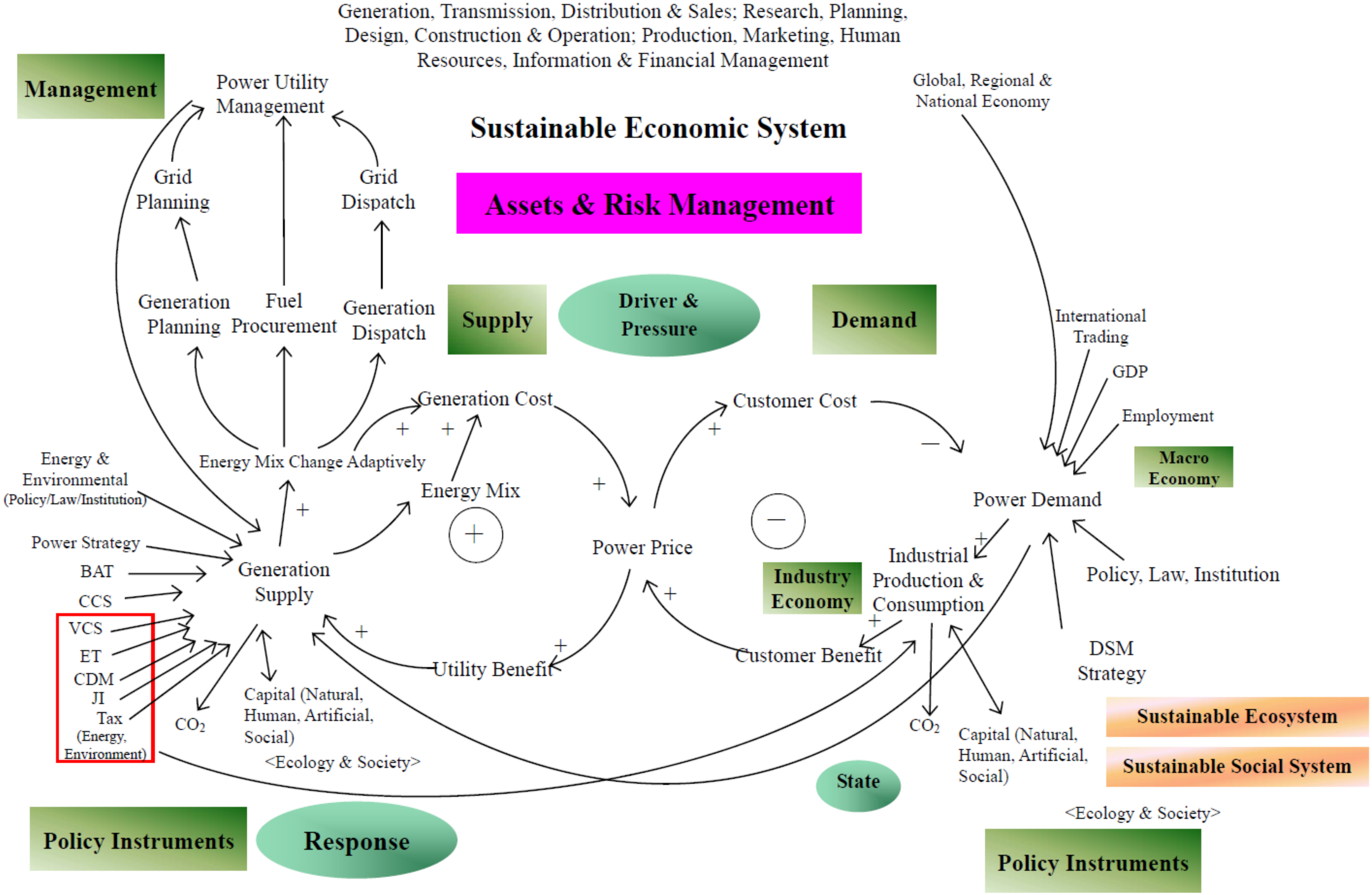
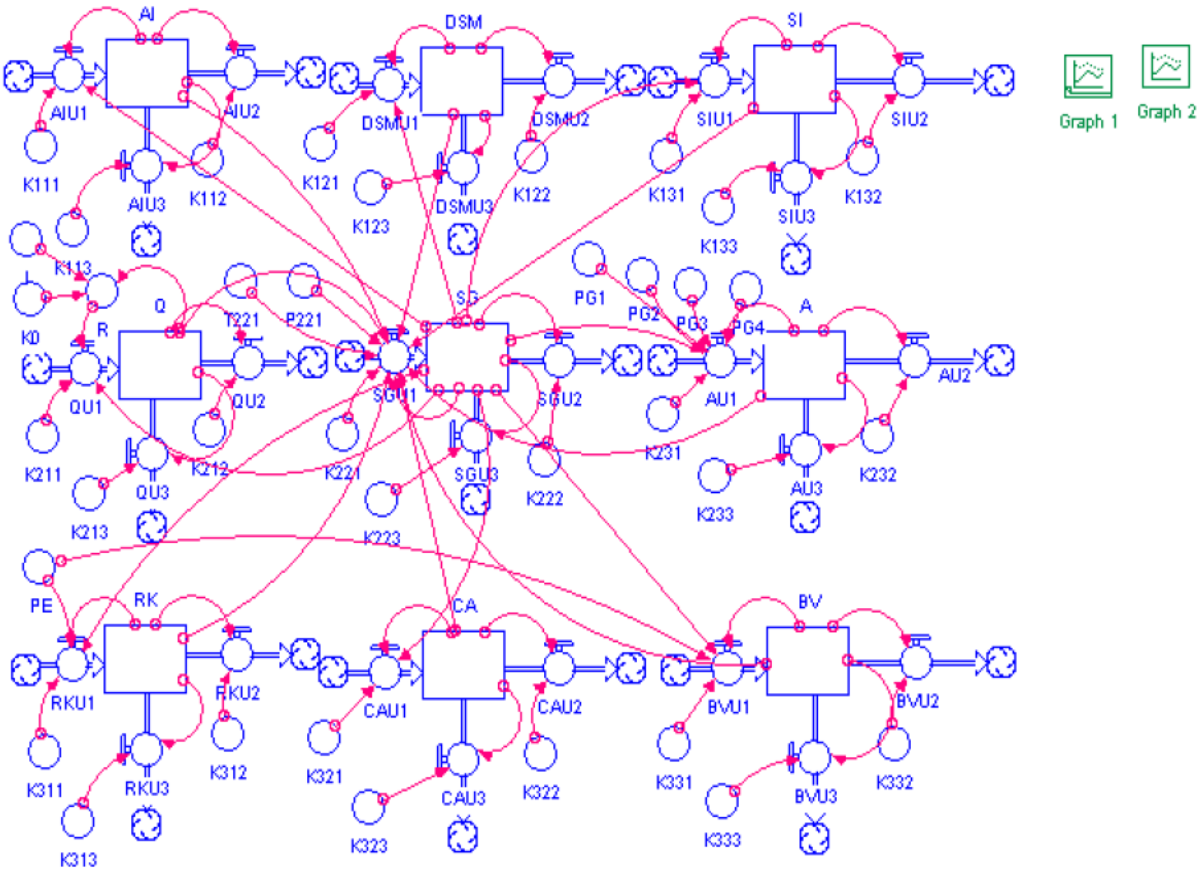


Fig 7：System Dynamic Simulation for Power Sustainable Development



Note：

AI：Adaptive Index

SI：Sustainable Index

BV：Value Index

RK：Risk Index

SG：Smart Grid

Q：Renewable Energy

A：Non-Renewable Energy

DSM：Demand Side Management

CA：Carbon Assets Management

U_1：Control of Energy Input

U_2：Control of Available Energy Output (i.e. Exergy)

U_3：Control of Unavailable Energy Output (i.e. Anergy, Entropy)

P_{221}：The Factors of Environment

T_{221}：The Factors of System

PG, PE：Energy Price

K：Parameter

State Variable(X)：SG, Q, A, DSM, CA

Measurement Variable (Y)：AI, SI

Objective (J)：BV, RK

Control Variable (U)：U_1, U_2, U_3

Fig 8：The System Dynamic Simulation for Power Sustainable System

Do agreements enhance energy efficiency improvement and emission reduction?
-Analyzing current scheme of negotiated agreements on industrial energy efficiency improvement and GHG emission reduction in South Korea

Seonghee Kim*

Summary

In 2009, Korean government has adopted Negotiated Agreements(NA) with energy incentive industry sector to improve energy efficiency and also enhance reduce GHG emissions as a main climate change policy. However, opinions differ concerning the usefulness of voluntary approaches such as NAs to achieve environmental targets. Voluntary approaches may offer a chance to address environmental problems in a flexible manner at a low cost, based on consensus building between the different stakeholders, the process which developing country is lacking usually. Such approaches, however, may provide few environmental improvements beyond what would have occurred anyway, while both administrative and abatement costs could be greater than using other instruments. Also, with regard to the requirements of national CO2 mitigation strategies, it has to be questioned whether NAs incorporate adequate reduction targets.

This study is aim to identify advantages and shortcomings of Korean NAs Scheme and provide some implications to lead Korean NAs to successful implementation from comparative analysis with international experiences.

1 Introduction

Regulators and industries are seeking adequate environmental protection at the lowest cost. This has led to the use of more flexible measures as market-based mechanism and voluntary approaches. Especially within the EU, voluntary initiatives from industry are considered to be a suitable complement and in some instances even an alternative to regulation and taxation oriented policy making – a development which reflects the industrial desire to gain more flexibility and freedom of choice.(Kristof and Ramesohl,1999)

In 2009, Korean government decided to adopt Negotiated Agreements(NAs) with energy incentive industry sector to improve energy efficiency and also enhance reduce GHG emissions. Thus NAs on energy efficiency improvement and GHG emission reduction will be the main climate change policy instrument in South Korea. Also, public finance would be provided to enhance compliance of NAs and to encourage investment to low carbon

* Researcher, Global Environment and Sustainable Development Unit, The Institute of Energy Economics, Japan (IEEJ)

technology. However, opinions differ concerning the usefulness of voluntary approaches such as NAs to achieve environmental targets. Voluntary approaches may offer a chance to address environmental problems in a flexible manner at a low cost, based on consensus building between the different stakeholders, the process which developing country is lacking usually. Such approaches, however, may provide few environmental improvements beyond what would have occurred anyway, while both administrative and abatement costs could be greater than using other instruments. Also, with regard to the requirements of national CO2 mitigation strategies, it has to be questioned whether NAs incorporate adequate reduction targets.

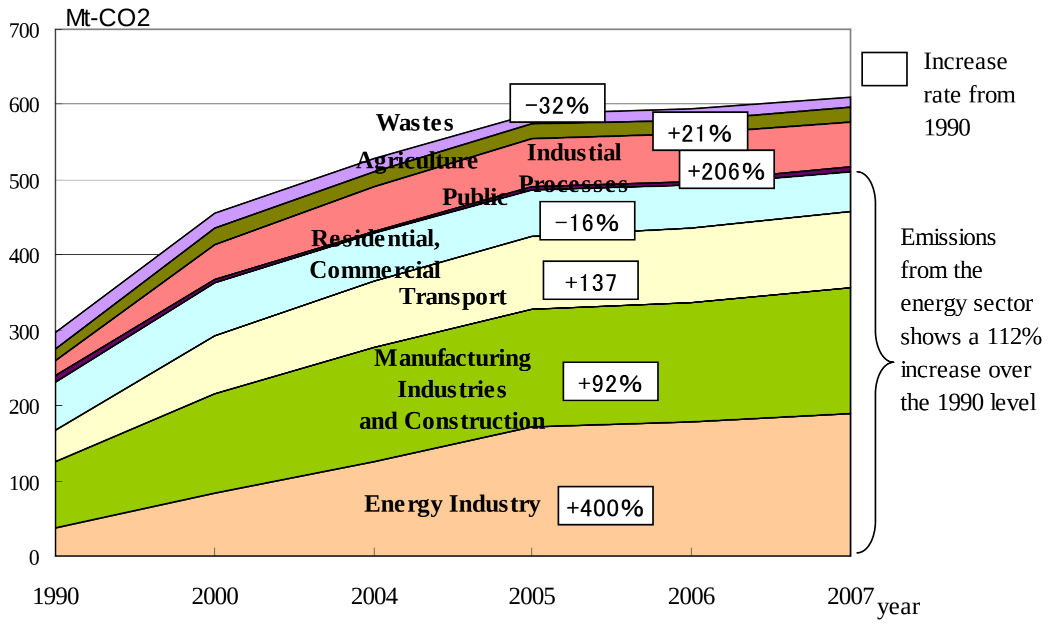
Taking the Korean industry's 'GHG and energy target management system' as an example, this paper discusses the major features of the Korean approach. This study aims to identify advantages and shortcomings of Korean NAs Scheme and provide some implications to lead Korean NAs to successful implementation. The results-together with a parallel review of Korean NAs- from comparative analysis of European and Japanese experiences with voluntary agreements will be the basis for assessing the potential effectiveness of Korean approach.

2 GHG emissions in Korea

Total GHG emissions of Korea in 2007 were 620 million tonnes (in CO2 eq.).(Figure 1) Figure 2 shows the breakdown of GHG emissions in 2007 by sector. The Energy accounts for 84.7% of total GHG emissions. GHG emissions from energy use in2007 were 525.4 million tones and increased by 112% compared to the emissions in 1990.

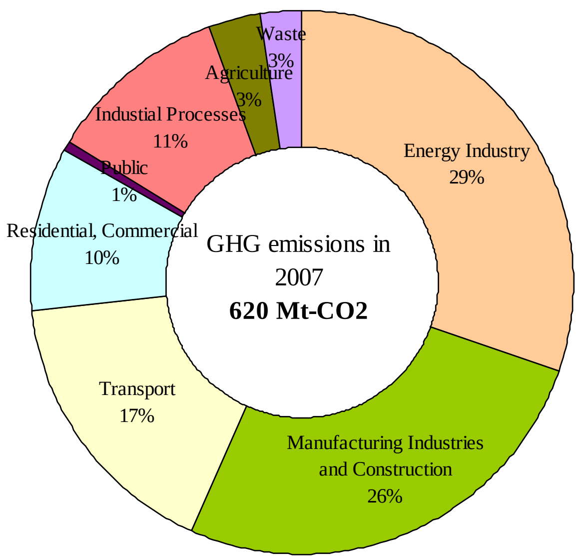
Industries are largest sources and represented 66% of GHG emissions in Korea. Residential sector accounts for 10% of GHG emissions in 2007 and emissions had decreased by 16% compared to the 1990 level. The primary reason for the emission reduction was the energy substitution policy from coal to clean energy as natural gas and electricity of 1990s. Total energy consumptions in residential sector are increasing continuously with the fast diffusion of household electrical appliances and comparatively low energy price.(Figure 3)

Figure 1. Greenhouse gas emissions in Korea 1990 to 2007, Trends by sector



Source: Green growth committee[1]

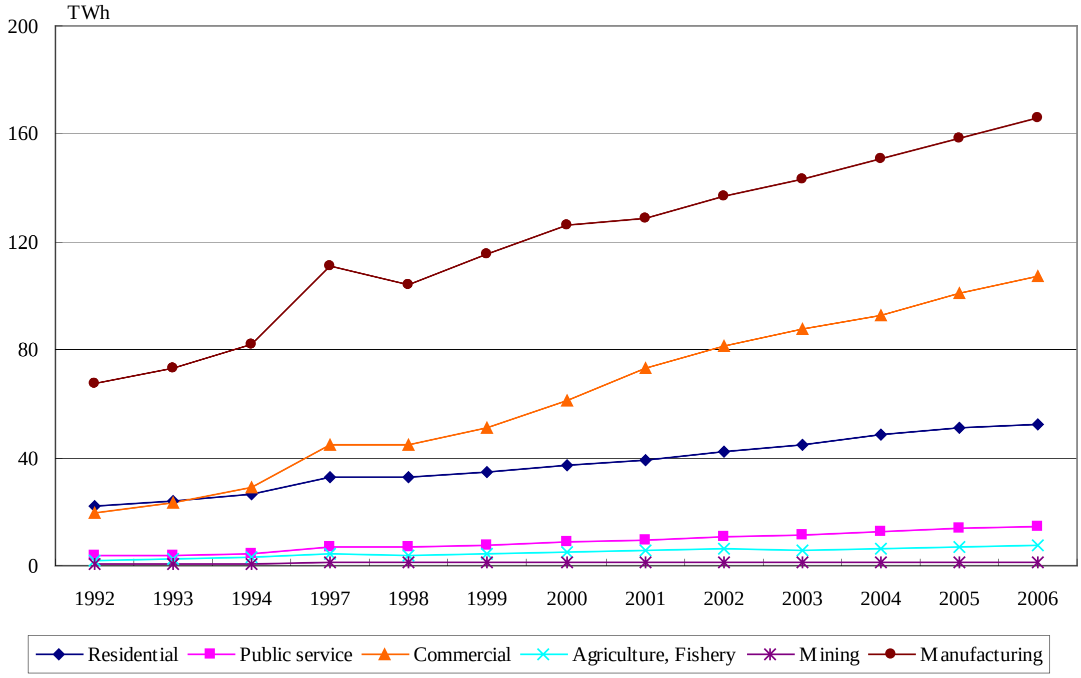
Figure 2. Greenhouse gas emissions by sector in 2007



Source: Green growth committee

[1] http://www.greengrowth.go.kr/www/policy/result/tong01/tong01.cms

Figure 3. Electricity consumption by sector, 1992 to 2006

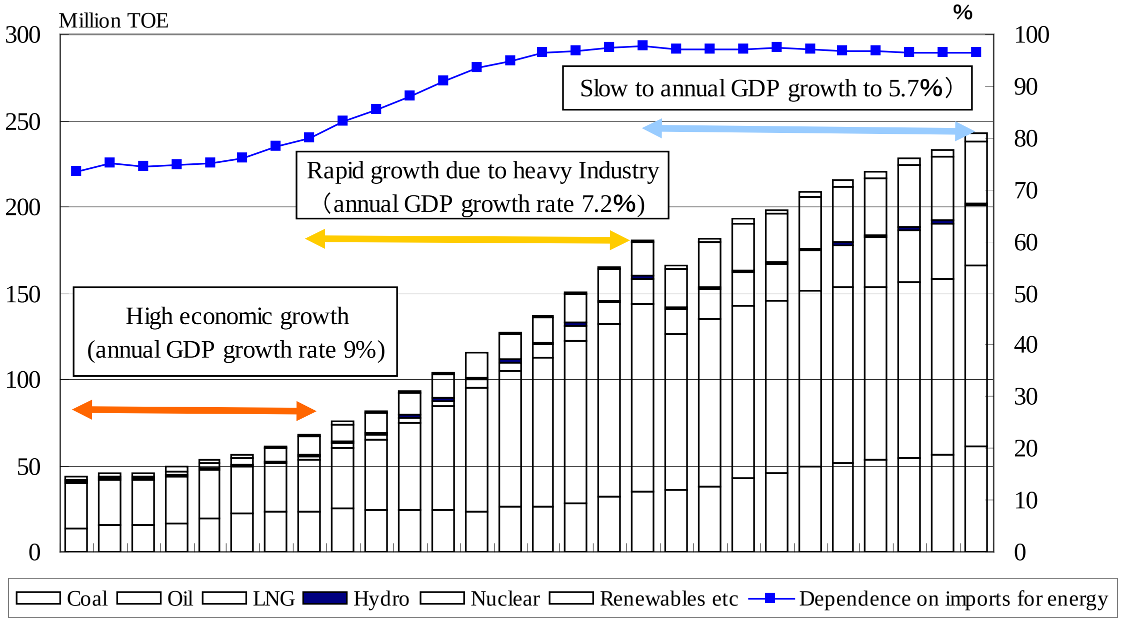


Source: Korean Statistical Information Service

Rapid GHG emissions increase is largely due to Korea's energy intensive economy structure. During the 1980s and 1990s, the Korean economy expanded rapidly, driven chiefly by heavy industrial sectors such as steel, shipbuilding, automobiles and chemicals. Figure 4 shows heavy dependence on fossil energy in Korea; Coal 43.6%, Oil 24.3%, Nuclear 15.9%, LNG 13.7% in 2006. Also, dependence on imports for energy was around 97% in 2006.

Growth rate of oil consumption is decreasing after economic crisis in 1997. During 1990 to 1997, oil consumption had increased by 11% annually, however annual growth rate dropped sharply to 1.5% after 1997. Coal consumption has increased to 59.7 million toe in 2006 by fourfold compared to 15.2 million toe in 1981 due largely to demand of power sector. Share of renewable was only 1.9% in 2007.

Figure 4. Trends in primary energy supply by source



Source: Korean Statistical Information Service

3 Korea's Climate Change Policy

At the 60th anniversary of the founding of the Republic of Korea on August 15, 2008, President Lee Myung-bak proclaimed "Low Carbon, Green Growth" as Korea's new national vision. This vision aims to shift the current development paradigm of quantity-oriented, fossil-fuel dependent growth to quality oriented growth with more emphasis on the use of new and renewable energy resources.

In order to facilitate the realization of the new vision, the Presidential Commission on Green Growth, 'Green Growth Committee', was established in February 2009. The National Assembly is deliberating on the enactment of the Framework Law on Low Carbon[2] Green Growth[3] which provides the legal and institutional basis for aligning all national and local rules and regulations under the overarching vision of green growth. To implement the national vision of green growth more effectively, the National Strategy for Green Growth was

[2] "low carbon" means lowering dependence on fossil fuels, expanding the use and distribution of clean energy, and reducing greenhouse gases to an appropriate or lower level by expanding carbon sinks(Article 2, provision1)

[3] "green growth" means growth achieved by saving and using energy and resources efficiently to reduce climate change and damage to the environment, securing new growth engines through research and development of green technology, creating new job opportunities, and achieving harmony between the economy and environment(Article 2, provision1)

adopted along with the Five-Year Plan for Green Growth. The National Strategy is divided into ten specific policy directions. (Figure 5)

The eruption of the financial and economic crisis in late 2008 resulted in a fall in the Korea's growth rate below 4 per cent in the fourth quarter of 2008. This is a significant reduction when compared to an average rate of growth of between 7 to 8 per cent in the last ten years.

Korea launched a "Green New Deal" on 6 January 2009 as a means of stimulating job creation and revitalizing the economy. The stimulus package, which is comprised of a mix of financial, fiscal and taxation policies, amounted to a total of US$ 38.1 billion, the equivalent of 4 per cent of Gross Domestic Product (GDP), to be implemented over the period 2009-2012. A total of US$ 30.7 billion (about 80 per cent of the total stimulus package) was allocated to environmental themes such as renewable energies (US$ 1.80 billion), energy efficient buildings (US$ 6.19 billion), low carbon vehicles (US$ 1.80 billion), railways (US$ 7.01 billion) and water and waste management (US$ 13.89 billion)

Figure 4. The three objectives and ten policy directions

Mitigation of climate change & energy independence	Creating new engines for economic growth	Improvement in quality of life and enhanced international standing
1. Effective mitigation of greenhouse gas emissions	4. Development of green technologies	8. Greening the land, water and building the green transportation infrastructure
2. Reduction of the use of fossil fuels and the enhancement of energy independence	5. The "greening" of existing industries and promotion of green industries	9. Bringing green revolution into our daily lives
3. Strengthening the capacity to adapt to climate change	6. Advancement of industrial structure	10. Becoming a role-model for the international community as a green growth leader
	7. Engineering a structural basis for the green economy	

Source: Green Growth Committee(2009)

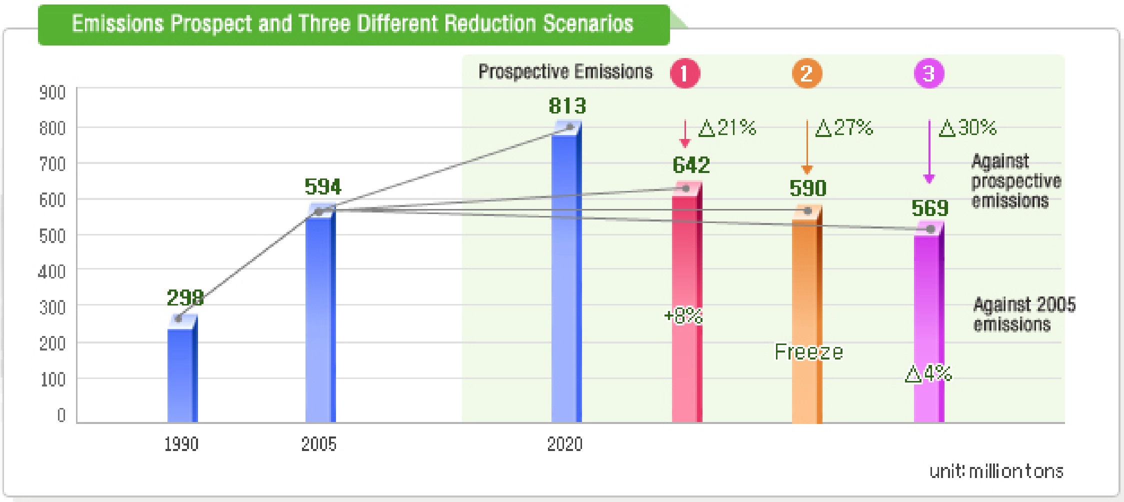
On 17 November 2009, the Green Growth Committee announced a decision taken at a cabinet meeting presided over by President Lee Myung-bak to adopt the most ambitious of the three options considered, that is a 30 per cent reduction of future emissions. Along with a mid-term mitigation goal, climate change initiatives laid out in the five-year green growth plan include the adoption of a legal and regulatory framework, carbon emissions trading, the creation by 2010 of a national GHG inventory report system, in addition to raising public awareness. Other measures announced include the adoption of new auto emission standards, a waste-to-energy programme to reduce GHG emissions from waste materials, promoting low carbon transportation, the introduction of light-emitting diodes (LEDs); stricter heat insulation standards for buildings, and development of carbon capture and storage (CCS) technologies. A Basic Law on Low-carbon and Green Growth, which was adopted by the Korean National Assemble in December 2009, provides the basic legislation for Korea's green growth strategy, including countermeasures on climate change.

Table 1. History of Korea's Climate Change Policy

2010.4.14	Enforcement of Framework Law on Low Carbon, Green Growth
2009.11.17	Confirmed the 30% target reduction of national greenhouse gas emission below prospective estimate of emission by 2020 (Cabinet Meeting)
2009.11.05	Presented the 27% or 30% draft target reduction of national greenhouse gas emission (below prospective estimate of emission)
2009.07.06	Finalized the Five-Year National Plan for Green Growth (Green Growth Commission 4th Session)
2009.02.25	Finalized government draft of Framework Law on Low Carbon, Green Growth
2009.02.16	Officially launched the first-phase the Green Growth Commission
2009.01.15	Proclaimed Presidential Decree on Establishment and Operation of the Green Growth Commission
2008.12	Organized preparatory TFT for the Green Growth Commission - Proclaimed establishment by enacting the Basic Act on Low-Carbon Green Growth and organizing the Green Growth Planning Bureau
2008.11	Organized preparatory TFT for the Green Growth Commission - Integrated review with National Commission against Climate Change, National Energy Commission, and National Commission on Sustainable Development

Source: Green Growth Committee website

Figure 5. Emissions Prospect and Three Different Reduction Scenarios



	Reduction target		Reduction policy selection criteria	Major reduction measures (example)
	Against BAU	Based on '05 emissions		
①	△21%	+8%	Introduce cost-efficient technologies and policies	・Green building/residential house Tightened demand-side regulation such as distribution of high efficiency facilities Revise transportation system with low-carbon scheme Expand the portion of new and renewable energy and nuclear energy Implement Smart Grid
②	△27%	Freeze	Introduce cost-efficient technologies and policies	・Eliminate fluorine gases with high global warming index(GWI) Expand the distribution of bio-fuels Partial introduction of CS
③	△30%	△4%	Maximum reduction amount for developing countries	・Distribute next-generation green car (electric car, fuel cell vehicle and etc.) Expand the distribution of high-efficiency household appliances Implement rigorous demand-side regulations

Source: Green Growth Committee website

4 Background of VA policy making

In 1998 the Korean government introduced the Voluntary Agreement (VA) system for promoting energy conservation in the industrial sector, which is currently employed by 1,355 enterprises and 190 buildings. However, it is assessed that the effect of energy conservation is decreasing due to conservative target level and low level of intention of the participating enterprises. The following Table 2 shows the effects of energy savings from 1999 to 2008 based on a document provided by the Sixth Green Growth Committee (as of November 5, 2009).

Table 1 Estimates of energy savings from 1999 to 2008

(Unit: %)

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Energy savings	3.4	2.1	2.2	1.9	1.7	1.6	1.3	1.9	2.5	1.7

Source: The Sixth Green Growth Committee (as of November 5, 2009)

In line with the steep rise of energy price and growing global pressure of GHG emissions reductions as an OECD country, it is required to strengthen conventional VA. In the Conference on Emergency Economic Measures (June 4, 2009), it was determined the introduction of the sector-wise target management system to effectively deal with climate change and attain energy independence. This sector-wise target management system is expected to enforce the effectiveness of the current VA by applying the Negotiated Agreement (NA).

Green Growth Committee formulated the enforcement plan for NA and reported at the sixth Green Growth Committee (November 5, 2009)., then was followed by enforcement of Framework Law on Low Carbon, Green Growth which stipulated implementation of NA in April 14,2010.

Before the Framework Law on Low Carbon, Green Growth came into effect, Ministry of Knowledge Economy introduced “Energy Management System” with 50 heavy energy consuming firms (500,000toe or more) as a trial scheme. However, with the enforcement of Framework law, a comprehensive negotiated agreement, “Greenhouse Gas Energy Target Management System (GETMS)” between government and energy intensive companies replaced the previous trial scheme of MKE.

The detailed policy for GETMS is not decided yet. This paper, therefore, assessed the scheme based on government document of public hearing, round-table conference with industry stakeholders and press material.

- Coverage

GHG emissions and energy consumptions of energy intensive industry, power plant, buildings, transport and waste will be covered from the start of the System. GETMS will include around 70 per cent of Korea's GHG emissions and involve mandatory obligations for around 600 entities.

- Point of obligation and threshold

GETMS obligations would apply to directly to large emitters-that is, to entities or facilities that have direct emissions of 125,000 tonnes of carbon dioxide equivalent a year more at the first year. Then the GETMS will expand the scheme coverage by lowering the threshold. There are two levels of scheme target-that is company and business site and these government designated entities will be called "controlled entities". Table 3 shows the each point of obligation and threshold.

Table 3. Point of obligation and threshold

	Level	GHG emissions	Energy consumption
2011	Companies	125,000t-CO2	500 terajoules
	Business Site	25,000t-CO2	100 terajoules
2012	Companies	87,500 t-CO2	350 terajoules
	Business Site	20,000 t-CO2	90 terajoules
2014	Companies	50,000 t-CO2	200 terajoules
	Business Site	15,000 t-CO2	80 terajoules

Source: 최광림(2010)

- Competent Organization

The Ministry of Environment (MOE) is in charge of coordination including preparation of scheme guideline, monitoring and designating of verification organizations. Other competent organization is in charge of negotiation, targets setting and performance evaluation. Following Table 4 and Table 5 show the each competent organizations by sector and each role.

Table 4. Competent organizations by sector

Sector	Competent organization
Agriculture, Livestock	MIFAFF(Ministry for Food, Agriculture, Forestry and Fisheris)
Waste	MOE (Ministry of Environment)
Industry, Power	MKE(Ministry of Knowledge Economy)
Buildings, Transport	MLTM(Ministry of Land, Transport and Maritime Affairs)

Source: MOE(2010)

Table 5. The role of each organization

Organization at stake	Role
Ministry of Environment	• Prepare comprehensive standards, procedures and guidelines • Monitor and evaluate the operation of competent organizations by sector • Designate and manage verification organizations
Competent organization by sector	• Designate NA entities • Set target • Evaluate performances

Source: MOE(2010)

- Target setting

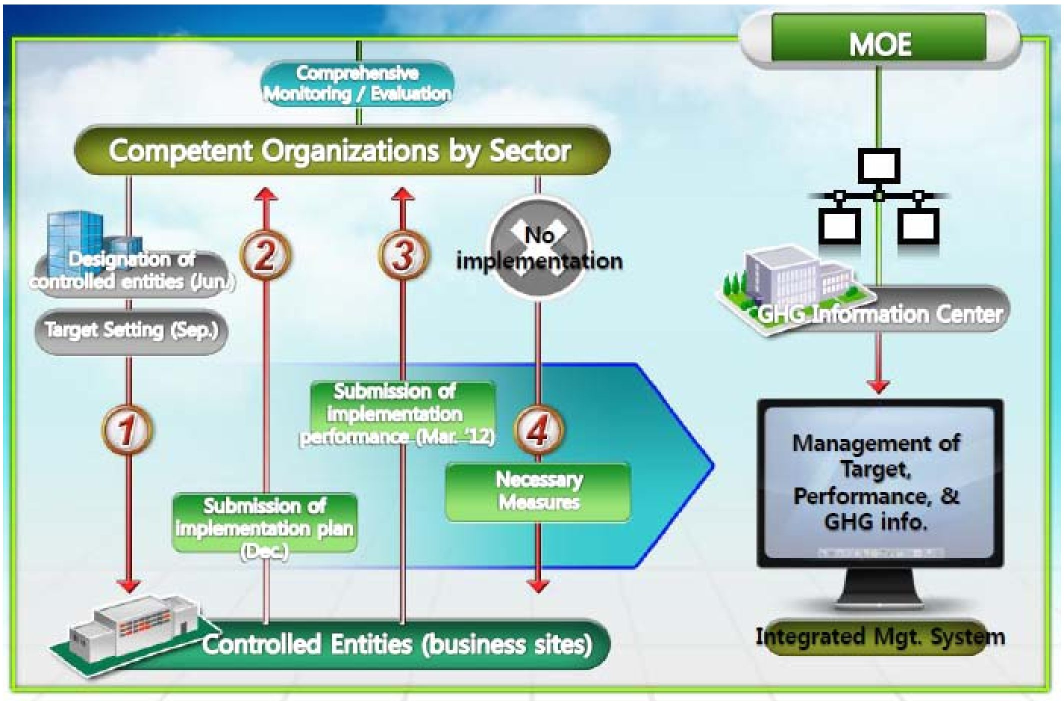
There are two levels of target which consist of sector-wise targets and entities-based targets. The former are set in cooperation with the national mid term reduction target of greenhouse gas emission, while the latter are determined on the basis of consultation in consideration of the past energy use data, technical level and international competitiveness of each entities. These targets would be absolute quantity in principle but power sector can select specific unit (i.e. per unit of production).

- Implementation process

The competent Ministries organize consultative body to set targets which consist of relevant ministries and experts then notify targets to controlled entities. The controlled entities have to submit annual target and implementation plan for the next 5 year. Implementation plan includes a) plan for GHG emission and mitigation, energy consumption and saving, b) calculation method for GHG emission and energy consumption, c) performance of GHG reduction, absorption, and removal. Then controlled entities report mitigation performance in accordance with implementation plan.(Mar. of the next year)

The competent organizations compile plans and submit them to GHG Information Center. Following Figure 6 shows the process of implementation.

Figure 6. The process of implementation



Source: MOE(2010)

- Further development

MOE and related government organization are developing the scheme rule and the announced schedule is as below.

- Guidelines for emission calculation and designation of controlled entities (Jul.2010)
- Notification on the designation of controlled entities (Sep.2010)
- Integrated guidelines for target management system (Sep.2010)
- Preparation submission of statements of past 3 years ('07-'09) and the previous year ('10) (Mar. 2011)

The establishment of calculation and management schemes will be mainly focused at the first year of scheme to provide preparation period for controlled entities.

5 Comparative analyses

In the field of climate change and energy efficiency, developed countries like EU and

Japan has adopted cooperative approaches that make use of negotiated instruments such as voluntary agreements. This section will focus on comparison with European and Japanese experiences with voluntary agreements to identify advantages and shortcomings of Korean NAs Scheme and provide some implications to lead Korean NAs to successful implementation.

Table 6 shows the each scheme design features. Experiences in developed countries indicate that there are several critical factors for the successful implementation of these voluntary approaches.

First, incorporating a comprehensive target setting with a time frame and a structured process organization are important success factors.

Second, monitoring procedures and methodologies are an important feedback mechanism to ensure compliance.

Third, external incentives and sanctions as well as the integration in a policy mix leads to a successful implementation of the policy instrument.

Forth, a policy culture of mutual trust between government and industry and homogeneousness of industry sector is supportive factors.

GETMS is more likely government regulation than traditional voluntary agreement in perspective of the scheme obligation and the penalty.

- Scheme participation

In voluntary agreement, scheme participation is not an obligation generally. Industry groups play important role in negotiated agreement. Industry groups become the platform where realizes energy saving potential in the industry sector by the cooperation between the companies who are competitors usually led by the industry groups. Also, industry groups provide assistance to each member companies for designing, monitoring and reporting. In Korean GETMS, these kinds of cooperative effect would hardly be realized for there are few room for industry group's intervention.

- Target setting

Whether they set sector-wide targets or not is dependent on each countries' situation. In UK and Netherlands, government plays leading role in the negotiation while industry groups set the targets unilaterally in Japan and Germany. In Korea, government sets the target following prior consultation with each company and business site. Also there are large flexibilities in selection of unit of targets in most cases.

Much of the criticism related VA's effectiveness indicates that VA may provide few environmental improvements beyond what would have occurred anyway-that is business as usual. In NA approaches, ex-post assessment is more common than ex-ante evaluation. UK's ex-ante evaluation method may provide good reference. In UK, the input to the negotiations is analysis by the Government's advisers (then called ETSU, now called Future Energy Solutions [FES], part of AEA Technology [AEAT]), which estimated the improvements in energy efficiency which the sector would be likely to achieve by 2010 in the absence of any CCL and CCAs (the business-as-usual (BAU) estimate), and the improvements which would arise if the sector implemented all cost-effective energy efficiency measures (the ACE estimate). The outcome of the negotiations is a target somewhere between the BAU and ACE estimates (Ekins and Etheridge, 2006).

- Incentives for compliance

There are two types of incentives encouraging compliance, one is direct incentives such as tax exemption of UK and linking of environmental license of Netherlands, the other is in-directive incentives such as regulatory risk which means stricter regulation would be introduce unless they achieved the target, in Germany and Japan. In Korea, financial penalty will be charged in non-compliance and some incentives are provide for over-compliance, for example, preferential treatment in loan application, green certificate, award, and recognition of mitigation performance when enacting emission trading system.

6 Conclusion remarks

Just 3-4 years ago, Korean were skeptical about GHG emissions mitigation action because Korea had no GHG emissions mitigation obligation under the Kyoto protocol. However economic crisis and a surge of global energy price have brought the paradigm shift to low carbon and green growth because Korea's economic growth had been backed by heavy energy intensive industry structure and it was clear that there came a limit of economic growth.

The Framework Law on Low Carbon, Green Growth stipulated to introduce almost whole measures which have been used or are being used in developed countries such as emission trading, carbon tax and negotiated agreement. Clearly, the aim of Korean NAs is to provide preparatory period to industry for Korea still lacks regulatory infrastructure. Compared with conventional NA in developed countries, Korean NA's administrative cost for negotiation can be high for the target is a company not an industry sub-sector. It is necessary to develop transparent method in incorporating a comprehensive target setting and process of assessing target ambitiousness. It is necessary also to analyze an interaction with other instruments such as emission trading and CO_2 tax to cope with double burden problem of target industry.

Table 6. Comparison of Negotiated Agreement- EU, Japan, Korea

	Netherlands	Germany	UK	Japan	Korea
Title	LTA1（1992） Benchmark Covenant(BC)（1999） LTA2（2001）	Declaration by German Industry and Trade on Global Warming Prevention （1995／1996／2000）	Climate Change Agreements（CCA、2001）	Voluntary Action Plan（1997）	Voluntary Agreement（1998） Greenhouse Gas Energy Target Management System (GETMS)（2010）
Entities	Industry group,Company	Industry group	Industry group,Company	Industry group	Company, Business site
Sector wide Target	Energy specific Unit LTA1：▲20％ LTA2：- BC：no quantity target	CO_2 specific Unit 1995：▲25％ from 1987 level 1996：▲20％ from 1990level 2000：▲20％ by 2005, ▲35% by 2012(GHG specific unit)	none	CO_2 emissions 1990 level annual average emissions from 2008-2012	CO_2 emissions, Coordinate with national mid-term target of 30% reduction from 2020 BAU
Sector Target	Energy specific Unit	Optional among Energy specific Unit, CO_2 specific Unit, CO_2 emissions	Optional among Energy specific Unit, Energy consumption, CO_2 specific Unit, CO_2 emissions	Optional among Energy specific Unit, Energy consumption, CO_2 specific Unit, CO_2 emissions	CO_2 emissions in principle, optional for power sector (CO_2 specific Unit)
Target Setting	Government leading negotiation with Industry group	Industry group leading(prior consultation with government)	Government leading negotiation with Industry group	Industry group leading	Government leading (prior consultation with Company)
Aim	Deregulation, To avoid climate change regulation	To avoid climate change regulation	Burden reduction of Climate change levy	Alternative of regulative measure	Building regulative infrastructure
Third party verification	Government organization (NOVEM) verify and disclose information annually	Private-sector institutions(RWI) check compliance and disclose information as annual report	Private-institutions (FES) check (every 2 year), Government (DEFRA) judge compliance and disclose information.	Industry Group (Keidanren) check and disclose information annually, Expert committee by Keidanren, Review of Government committee	Third party Verification, Government disclose information
Penalty	Linking to environmental approval and license	None(Risk of regulative measure introduction)	No exemption of CCL	None	Surcharge

Source: 金・工藤（2007）

Reference

English

P. Ekins and, B. Etheridge (2006) The environmental and economic impacts of the UK climate change agreements, Energy Policy 34 (2006) pp2071–2086

S. Krarup and S. Ramesohl (2002) Voluntary agreements on energy efficiency in industry — not a golden key, but another contribution to improve climate policy mixes, Journal of Cleaner Production 10 (2002) pp109–120

Ministry of Environment (MOE) (2010) Greenhouse Gas Energy Target Management System, April 14 2010.

Green Growth Committee (2009) Road to Our Future : Green Growth-National Strategy and the Five-Year Plan (2009~2013)

Japanese

金星姫、工藤拓毅 (2007)「温暖化防止自主協定の評価に関する調査―オランダ、ドイツ、イギリスの事例研究」『エネルギー経済』2007 年 12 月号、日本エネルギー経済研究所

Korean

최광림 (2010) 에너지목표관리제 와 기업의대응방안 대한상공회의소 지속가능경영원

Research on Carbon Dioxide Emissions in China

–emission situation, background and the feasibility of reduction target

Wang Lei, Yoshida Fumikazu

Ⅰ Introduction

Climate change is a serious problem worldwide and the international community has a great interest in this problem. Many changes in the global climate system have been caused of global warming, and also expected to affect the future of human being significantly. China, as developing country is facing severe problems of climate change. China has clearly changed in the climate in 100 years. According to the latest observations of the China Meteorological Administration, the last 100 years, average annual temperature in China rising 0.5～0.8 ℃, exceeding slightly the average width of temperature rise in the world during the same period, the warming of the last 50 years especially prominent. In China, the future seems to trend towards greater climate change. In 2020, China's annual average temperature will increases from 1.3 to 2.1 ℃ compared with 2000, in 2050 is projected to rise 2.3 to 3.3℃. The next 100 years, the frequency of incidents and potential climate anomalies in China is growing and the change will give a great influence on people's lives and social development has become clear.

In recent years China achieve high economic growth rate, carbon dioxide emissions are growing rapidly, surpassing the U.S. in 2008, became the world's largest carbon dioxide emitting country. China's measures against global warming, has been focused from the world.

Therefore, the purpose of this research is to examine the current emissions of energy-related CO_2 in China, focusing on the characteristics of energy use in China, the situation of CO_2 emission, and the possibility of reduction target by 2020 that had been submitted by the Chinese government in 2009.

Since the economic reforms of 1978, China has recorded an average real growth rate exceeding 9% a year. Per capita real income has increased almost tenfold during this period (Ang, JB 2009). There are so many research using different methods to find the characteristics of China CO_2 emissions and the background. There is no doubt that China's CO_2 emissions increased dramatically, and the driving factors are economic activity, increasing population, international trade, urbanization, infrastructure, large energy consumption, increased capital investment, lower energy efficiency and so on. Ang (2009) has adopted an analytical framework that combines the environmental literature with modern endogenous growth theories, and the results indicated that CO_2 emissions in China are negatively related to research intensity, technology transfer and the absorptive capacity of the economy to assimilate foreign technology, more energy use, higher income and greater trade openness tend to cause more CO_2 emissions. Zhang (2009) used the complete decomposition method IPCC model to analyze the nature of the factors that influence the changes in energy-related CO_2 emission and CO_2 emission intensity during the period 1991–2006. They found that: (1) energy intensity effect is confirmed as the dominant contributor to the decline in CO_2 emission and CO_2 emission intensity, (2) economic activity effect is the most important contributor to increased CO_2 emission, and (3) economic structure and CO_2 emission coefficient effects are found to contribute little to the changes in CO_2 emission and CO_2 emission intensity, which actually increased CO_2 emission and CO_2 emission intensity over the period 1991–2006 except for several years.

The research about administrative regions CO_2 emission like Hu (2006) analyzes energy efficiencies of 29 administrative regions in China for the period 1995–2002 with a newly introduced index. Based on the TFEE (total-factor energy efficiency) index rankings, the central area of China has the worst energy efficiency and its total adjustment of energy consumption amount is over half of China's total. Regional TFEE in China generally improved during the research period except for the western area. A U-shape relation between the area's TFEE and per capita income in the areas of China is found, confirming the scenario that energy efficiency eventually improves with economic growth.

The relationship between CO2 emissions and trade, Yan (2010) applying an input–output approach, estimated the amount of carbon dioxide (CO_2) embodied in China's foreign trade during 1997–2007. They found that 10.03–26.54% of China's annual CO_2 emissions are produced during the manufacture of export goods destined for foreign consumers, while the CO_2 emissions embodied in China's imports accounted for only 4.40% (1997) and 9.05% (2007) of that. During 1997–2007, the net "additional" global CO_2 emissions resulting from China's exports were 4894 Mt. They found that scale and composition effect increased the CO_2 emissions embodied in trade while the technical effect offset a small part of them. Guan (2009) adopting a structural decomposition analysis, a macro-economic approach to investigate the drivers of China's recent CO_2 emissions surge. They found that Chinese export production is responsible for one-half of the emission increase. Capital formation contributes to one-third of the emission increase. A fast growing component is carbon emissions related to consumption of services by urban households and governmental institutions, which are responsible for most of the remaining emissions.

Decomposition of CO_2 emission has recently been an actively researched field. Wu(2005) argued that the speed of decrease in energy intensity and a slowdown in the growth of average labor productivity in the industrial sectors were the dominant contributors to the sudden changes of energy-related CO_2 emission in the period 1996–1999. Wu(2006) used the Log-Mean Divisia Index (LMDI) method to study CO_2 emission from 1980 to 2002, and concluded that before 1996 economic scale, fuel mix and energy intensity on the energy-demand side mainly drove the changes in China's CO_2 emission, and the structure and efficiency changes on the energy-supply side played only a minor role. Moreover, over the period 1996–2000, the acceleration of efficiency improvement in end-use and transformation sectors accounted for the decline in China's CO_2 emission that were related to the total primary energy supply. Wang(2006) concluded that the total theoretical decrease of CO_2 emission was 2466 Mt during 1957–2000, of which about 95% of the total decrease could be attributed to energy intensity decline, and only 1.6% and 3.2%, respectively, can be attributed to fossil fuel mix and renewable energy penetration based on the LMDI decomposition method. Fan(2007) show that industry structure partly offsets the decline impact over the period 1987–2002, and the change in final energy mix also partly offsets the decline impact of energy intensity on carbon intensity in carbon intensity over the period 1981–2002, which suggests that final energy use in material production sectors become carbon intensive, and that the development of material production sectors also become carbon intensive.

This paper is different from above literature researches. The literature researches used LMDI method that ignored the analysis of the characteristics of energy consumption change, that is important for analyze the CO_2 emission in China. We use the LMDI method but the research period is different, we also make a particular analysis about the change of energy consumption, and the most important, we set three scenarios to do an original analysis about the feasibility of China's reduction target by 2020.

Consequently, this paper analyzes the characteristics of energy consumption and energy-related CO_2 emission over the period 1990-2008. The aim of the paper is to identify the characteristics of energy-related CO_2 emission in China, the correlation between the factors and emissions, and the most important is to analyze the feasibility of reduction target by 2020.

The article is organized as follows. Section 2 describes the LMDI method and the data used. Section 3 presents the characteristics of energy consumption of China, and the section 4 present the characteristics of energy-related CO_2 emission in China, and the correlation of the factors and emissions. Section 5 analyzes the feasibility of reduction target. Section 6 presents conclusions.

Ⅱ Methodology

There are various methods available for analyzing the changes in emissions. Introduced in the late 1970s to study the impact of structural change on energy use in industry, index decomposition analysis has been extended and used in several other application areas for policymaking. The simplicity and flexibility of the methodology make it easy to be adopted as compared to some other decomposition methodologies, such as the input–output structural decomposition analysis where input–output tables are needed (B.W. Ang 2004). The popular decomposition methods among analyses can be divided into two groups: methods linked to the Laspeyres index and methods linked to the Divisia index. The Laspeyres index measures the percentage change in some aspect of a group of items over time, using weights based on values in some base year. The Divisia index is a weighted sum of logarithmic growth rates, where the weights are the components' shares in total value, given in the form of a line integral (B.W. Ang 2004). Ang (2004) compared various index decomposition analyses, and concluded that the LMDI method is the preferred method, due to its theoretical foundation, adaptability, ease of use and result interpretation, along with some other desirable properties in the context of decomposition analysis. Ang and Liu (2007) pointed out that the results based on LMDI decomposition do not contain an unexplained residual term, and that all zeros in the data set may be replaced by a small positive constant.

Therefore, this paper uses LMDI method to analyze the energy-related CO_2 emission in China during the period 1990-2008.

We define the variables $\mathbf{E}_i$ as the energy consumption of carbon-based fossil fuel, **E** as the total energy consumption, *Y* as GDP, and *P* as the population. China's total energy-related CO_2 emission can be expresses by the Kaya identity, as given follows.

$$\mathbf{C = \Sigma C_i = \Sigma (C_i / E_i) (E_i / E) (E / Y) (Y / P) P}$$

Where C is the total energy-related emissions CO_2 emissions; $\mathbf{(C_i / E_i)}$ is the mean CO_2 emission coefficient of fossil fuels by each type; $\mathbf{(E_i / E)}$ is the fuel share in total energy consumption; **(E / Y)** is the energy intensity; **(Y / P)** is the GDP per capita.

The data used in this paper, were taken from "China Statistical Yearbook (2009 Edition)", the total energy consumption cover not only by manufacturing industries, but also by agriculture, construction, service, office and households.

Results: 1990 as the base year, 1990-2008 the average annual growth rate of CO_2 emission is

6.2%, the average annual growth rate of per capita is 5.3%, the annual population growth rate is 0.84%, annual per capita GDP growth rate is 16%, annual GDP growth rate is 17%, annual energy consumption per GDP is -8.9% respectively.

Due to the LMDI method, the CO_2 emission driving factor will be divided into five parts: energy consumption type, energy intensity, per capita GDP, population, and the mean CO_2 emission coefficient of fossil fuels.

Therefore, based on the LMDI method, the reduction policy can be expended major in the conversion to renewable energy, usage of low-carbon energy, reduction the population, improvement the energy efficiency and technology, protection the ecological system, usage the economic methods and so on.

Ⅲ Characteristics of energy consumption in China

Since the founding of China, especially since the reform and opening up, energy consumption and economic growth increase rapidly. As shown in Figure 1, the gross domestic product in 1978 was 0.36 billion yuans, in 2008 increased to 30.67 million yuans, the annual growth rate is 10%. The total energy consumption in 1978 was 5.71 billion tons (equivalent to standard coal), in 2008 billion was increase to 28.50 billion tons (with a standard coal equivalent) , approximately 30 years after the reform and opening up (1978-2008 year), the annual growth rate of energy consumption reached about 6.0 %.

China's total energy consumption in 2008 increased 7.3% compared with the previous year. Total consumption of raw coal in 2007 was 25.8 million tons, compared with 2005 increased 19.3 %. Total consumption of oil was3.4 billion tons, compared with 2005 increased 12.4 %. Total electric power consumption was 3.3 million billion KWh, compared with 2005 increased 31.2%.

Chart 1: The total energy consumption and GDP of China (1978 – 2008)

Year	Total energy consumption (million tons standard coal)	GDP (billion million yuans)	Consumption per GDP (ton standard coal / yuans)	Year	Total energy consumption (million tons standard coal)	GDP (billion million yuans)	Consumption per GDP (ton standard coal / yuan)
1978	5.71	0.36	15.68	1998	13.22	8.44	1.57
1980	6.03	0.45	13.26	1999	13.38	8.97	1.49
1985	7.67	0.90	8.51	2000	13.86	9.92	1.40
1990	9.87	1.87	5.29	2001	14.32	10.97	1.31
1991	10.38	2.18	4.76	2002	15.18	12.03	1.26
1992	10.92	2.69	4.05	2003	17.50	13.58	1.29

1993	11.60	3.53	3.28	2004	20.32	15.99	1.27
1994	12.27	4.82	2.55	2005	22.47	18.32	1.23
1995	13.12	6.08	2.16	2006	24.63	21.20	1.16
1996	13.89	7.11	1.95	2007	26.55	24.95	1.03
1997	13.78	7.90	1.74	2008	28.50	30.67	0.95

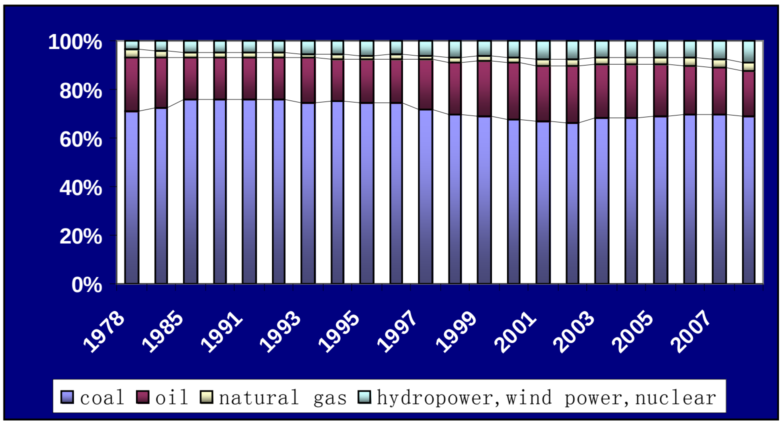
Source: "China Statistical Yearbook (2009)," created by author

The rapidly increasing energy consumption would give maximum pressure on energy supply. China's crude oil export in 1995 was 2.45 million tons, while import was 3.67 million tons, accounting for 22.86% of the total consumption 16.06 million tons. In 2000, the export was 2.17 million tons, while the import was 9.75 million tons, accounting for the total consumption percentage was double to the 1995, was 43.44%, respectively. In 2007 the export of crude oil was 2.66 million tons, the import increased to 21.14 million tons, occupied 57.80% of the total consumption, in 2007, the dependence on imports for consumption was more than 50 percent.

For raw coal export in 1995 was 1.73 million tons, while import was 0.2 million tons, accounting for 0.19% of the total consumption 105.52 million tons. In 2000, exports increased to 5.51 million tons, while import was 0.22 million tons, down slightly compared with 1995, occupied 0.17% of the total consumption, respectively. In 2007 the export was 5.32 million tons, while import was 5.10 million tons, accounting for 1.97% of the total consumption 258.64 million tons, the import volume increased 10 times compared with 1995.

Based on the natural distribution of energy, in China coal becomes the central consumption energy. The percentage of coal occupied the total energy consumption in 1978 was 70.7%, in 2000 was 67.8%, and in 2007 was 69.5%. The proportion of oil in 1978 was 22.7%, in 2000 was 23.2%, and in 2007 was 19.7%. The proportion of natural gas in 1978 was 3.2%, in 2000 was 2.4%, and in 2007 was 3.5%, returned to 1978 levels again. Renewable energy such as hydropower and wind power, nuclear is increasing continually, the proportion in 1978 was 3.4%, in 2000 was 6.7%, and in 2007 was 7.3%. As shown in figure 2, the usage of renewable is increasing, but the coal is still accounting for the central energy consumption structure.

Figure 2: The energy consumption structure of China (1978-2008)



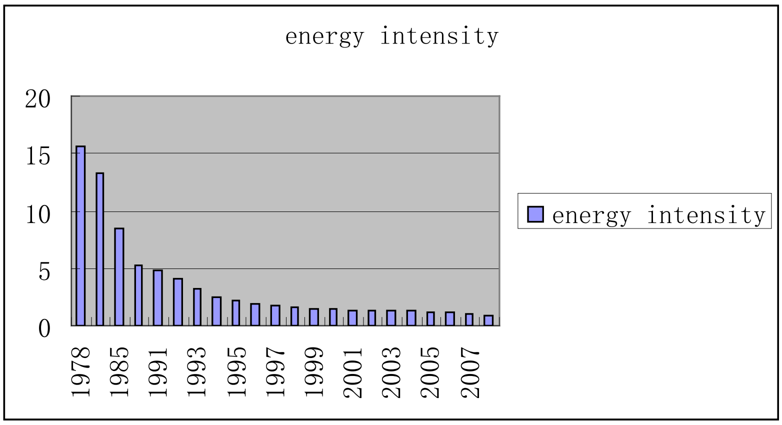
Source: "China Statistical Yearbook (2009)," created by author

At the sector level, industry is the largest consumer. The total energy consumption in 2007 was equivalent to 265.58 million standard coal tons, the consumption of the industrial sector was 190.17 million tons, accounting for 71.6 % of total consumption. In addition, the proportion of construction sector was 1.5%, transportation sector was 7.77%, and agricultural and forestry sector was 3.1%. In the industrial sector, the manufacturing sector accounted for 58.8% of the total consumption. In 2007, Industrial sector consumed raw coal, coke, crude oil accounted for 94.8%, 99.2%, 99.5% of the total consumption, respectively. Particularly the raw coal, coke, crude oil consumption of manufacturing industry accounted for 36.4%, 98.3 %, 95.96% of the total consumption. Even now industry is the core sector, for these situations the implementation of measures such as improvement of energy efficiency and adjustment industrial structure now become the urgent task.

The low energy efficiency also must be solved. According to " long-term specialist energy saving plan ", in 2000 (calculated at 2007 charge) China's energy consumption per millions dollars GDP was 1274tons standard coal, which was higher than the world average level 2.4 times, also higher than the United States 2.5 times, EU 4.9 times, Japan 8.7 times, respectively.

With the adjustment of industrial structure and technological progress since 1978, annual growth rate of energy consumption is less than the annual growth rate of GDP, so the energy consumption per GDP in China, which is a downward trend. In 1978, the energy intensity was 15.7 tons standard coal per yuan, in 1998 was 1.57 tons standard coal per yuan, decreased to about 10 times. In 2008, the energy intensity was 0.95 tons standard coal per yuan.

Figure 3: Energy intensity in China between 1978 and 2008



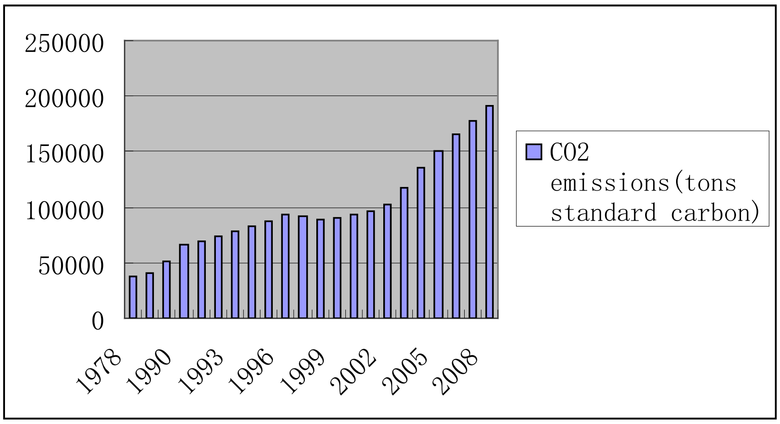
Source: "China Statistical Yearbook (2009)", created by author

Ⅳ China's carbon dioxide emissions situation

1 Status of total emissions

Since the reform and opening up in 1978, followed the energy consumption structure and rapid economic development, the CO_2 emission increased dramatically. According to LMDI model, used the data from "Statistical Yearbook of China (2009 edition)" to calculate the CO_2 emissions, the results shown in figure 4.

Figure 4: Total carbon dioxide emissions of China (1990 - 2008)



Source: the results calculated by author used LMDI method

And, the results of CO_2 emissions annual growth rate are expressed in Chart 5.

Chart 5: CO_2 emissions annual growth rate (%) (1990 - 2008)

1990-1991: 5.1	1999-2000: 3.5
1991-1992: 5.2	2000-2001: 3.4
1992-1993: 6.2	2001-2002: 6.0

1993-1994: 5.8	2002-2003: 15.3
1994-1995: 6.9	2003-2004: 16.1
1995-1996: 5.9	2004-2005: 10.6
1996-1997: -0.8	2005-2006: 9.6
1997-1998: -4.0	2006-2007: 7.8
1998-1999: 1.2	2007-2008: 7.3

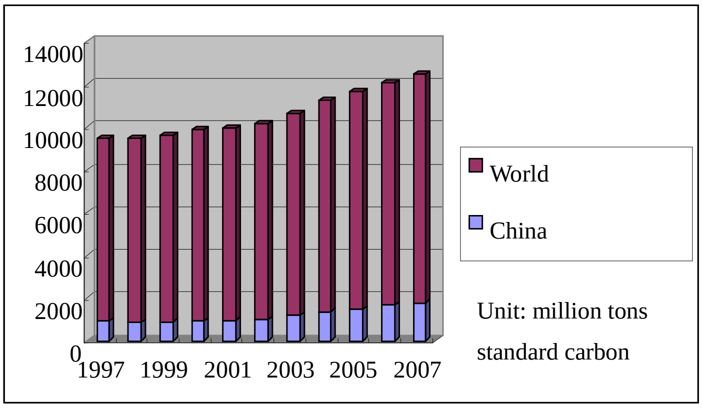
Source: the results calculated by author used LMDI method

Based on LMDI model, we got the results that from 1990 to 2008 CO_2 emissions annual growth rate was 6.2%, particularly after 2002, was found to increase significantly. Because of the 1998 Asian financial crisis, the growth rate from 1996 to 1998 was the negative. In 2001 China joined in WTO, due to the rise of export and investment absorption, CO_2 emissions increased significantly.

2 Historical cumulative amount

The share of global emissions of CO_2 emissions from China are increasing, but that are the small amount of emissions compared to industrialized countries at synchronous development stages. In 2000, China's CO_2 emission was 9.28 trillion tons standard carbon, occupied 10.4 % of the world's total emissions, 41.9% of U.S. emissions. In 2005, China's CO_2 emission was 10.05trillion tons standard carbon, occupied 14.8 % of the world's total emissions, 66.6% of U.S. emissions. According to "China Energy Report (2008)", looking at the amount of cumulative historical emissions, in 1910-1950, the United States emissions occupied more than 40% of world's total emissions, in 1910-1940, Europe occupied more than 20% of world's total emissions, but in 1900-2004, China's CO_2 emission only occupied 8% of world's total emissions.

Figure 6: the rate of China's CO_2 emission occupied world's total emissions (1997 - 2007)



Source: "BP World Energy Yearbook (2008)," created by author

3. Emissions per capita

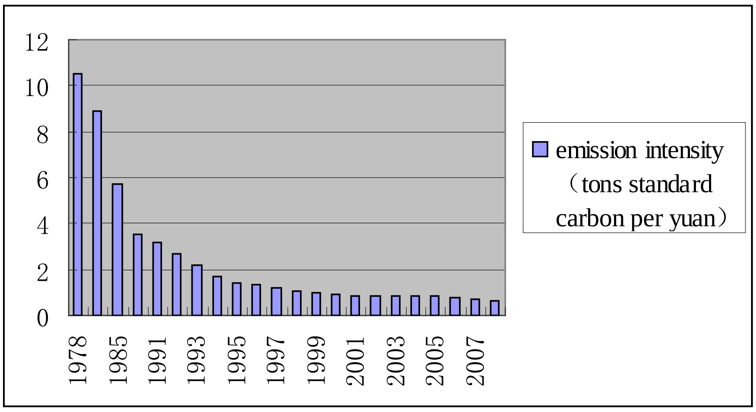
CO_2 emission per capita in China is lower than the average level of the world. We use the data from "BP World Energy Yearbook" to calculate, the results indicated that in 2000, the CO_2 emission per capita in China was 0.73 tons(equivalent in standard coal), in U.S. was 5.76 tons, in

Japan was 2.61 tons, in Western Europe was 1.74 tons, and the world's average CO_2 emission per capita was 1.47 tons, China's per capita emissions level accounted for only 49.6 % of the world average level. In 2004, the CO_2 emission per capita in China was 1.05 tons(equivalent in standard coal), in U.S. was 5.62tons, in Japan was 2.69 tons, in Western Europe was 1.86 tons, and the world's average CO_2 emission per capita was 1.55 tons, China's per capita emissions level accounted for only 67.7% of the world average level.

4. Emission intensity

From 1978 to 2008, we can see the decreasing trend at CO_2 emissions per GDP in China. In 1978, China's emission intensity was 10.5 kg standard carbon per yuan, in 1998 was 1.05 kg standard carbon per yuan, decreased 10 times. In 2008, the China's emission intensity was 0.64 kg standard carbon per yuan.

Figure 07: The change of emission intensity in China (1978 - 2008)



Source: author created with results obtained by LMDI model

5 The correlation of factors

According to previous studies, the driving factors, are economic activity, increasing population, international trade, urbanization, infrastructure, large energy consumption, increased capital investment, lower energy efficiency and so on. In this paper, we calculated the correlation between CO_2 emissions and factors, the result is displayed in the chart 8.

Chart 8: the correlation coefficient between CO_2 emissions and driving factors (1990-2008)

CO_2 emissions and GDP	0.984
CO_2 emissions and population	0.86
CO_2 emissions and investment	0.987
CO_2 emissions and energy intensity	-0.662
CO_2 emissions and exports (2004-2008)	0.995

The results show that investment has the biggest positive effect in CO_2 emissions, also economic activity (GDP) and exports, and China has achieved a considerable decrease in CO_2

emissions mainly due to energy intensity.

Ⅴ Feasibility of reduction targets by 2020

On 27 November 2009, Chinese government manifested the reduction target that CO_2 emissions per GDP will be reduced 40-45% compared with 2005. This is the first time that China shows the CO_2 emissions reduction numerical targets. Now this is a question that whether or not this reduction targets can be realized, and how to realize it, this paper has analyzed the feasibility of this reduction target.

In this paper, three scenarios have been set, scenario A, scenario B, and scenario C. The GDP in scenario A, B, C is the same, 44.95 trillion yuans. According to the decision of the 17th Chinese Communist Party Congress, in 2020, the capita per GDP will be 4 times compared to 2000, so we set the capita per GDP to be 31432 yuans, and we consider the increasing population situation, set the population in 2020 will be 14.3 billion people, so we can get the GDP in 2020, that is 44.95 trillion yuans. In 2000, the total energy consumption was 13.9 billion tons standard coal, based on this we set that in scenario A, in 2020 the total energy consumption is 2 times compared 2000, 27.7 billion tons standard coal, in scenario B is 3 times compared 2000, 41.6 billion tons standard coal, and in scenario C, is 55.4 billion tons standard coal, 4 times compared 2000. We use LMDI model to calculate the CO_2 emissions. About the usage of renewable energy, according to "long-term renewable energy development plan", in 2010 the energy saving is 3 billion standard carbon, and in 2020 is 6 billion standard carbon. The results are shown in chart 9.

Chart 9: Scenario analysis for reduction targets by 2020

	Scenario A	Scenario B	Scenario C
2020 the gross domestic product (trillion yuans)	44.95	44.95	44.95
Total energy consumption in 2020 (billion tons of standard coal)	27.7	41.6	55.4
CO_2 emissions per GDP (tons / million Yuan)	1.52	2.27	3.03
achieved by saving energy	49.7%	24.6%	-0.005%
the Renewable Energy alternatives	21.7%	14.4%	10.8%
Total	71.4%	39.0%	10.7%

As shown in chart 9, to achieve reduction targets the biggest influence factor is the total energy consumption. The more energy we consume in 2020, the more difficult to realize the reduction target. To achieve this reduction target, the total energy consumption must be strictly controlled within three times of 2000.

Ⅵ Conclusion

Since the founding of China, especially since the reform and opening up, energy consumption and economic growth increase rapidly. In 1978-2008, the GDP annual growth rate is

10%. the annual growth rate of energy consumption reached about 6.0 %. The rapidly increasing energy consumption would give maximum pressure on energy supply. In 2007, the dependence on imports for consumption was more than 50 percent. At the sector level, industry is the largest consumer, in 2007 was accounting for 71.6 % of total consumption.

Followed the energy consumption structure and rapid economic development, the CO_2 emission increased dramatically. Based on LMDI model, we got the results that from 1990 to 2008, CO_2 emissions annual growth rate was 6.2%, particularly after 2002, was found to increase significantly. For the 1998 Asian financial crisis, the growth rate from 1996 to 1998 was the negative. In 2001 China joined in WTO, due to the rise of export and investment absorption, CO_2 emissions increased significantly. The share of global emissions of CO_2 emissions from China are increasing, but that are the small amount of emissions compared to industrialized countries at synchronous development stages. CO_2 emission per capita in China is lower than the average level of the world. In this paper, we calculated the correlation between CO_2 emissions and factors, the results show that investment has the biggest positive effect in CO_2 emissions, also economic activity (GDP) and exports, and China has achieved a considerable decrease in CO_2 emissions mainly due to the decrease of energy intensity.

In this paper, we set three scenarios to analyze the feasibility of reduction target by 2020, we got the conclusion that to achieve reduction targets the largest factor is the total energy consumption. The more energy we consume in 2020, the more difficult to realize the reduction target. To achieve this reduction target, the total energy consumption must be strictly controlled within three times of 2000.

With the development of China's economy, there will be continuing emission of CO_2, we predicts that this situation can not be changed in short-time. The reduction mainly achieved by the usage of renewable energy, energy conservation, adjustment the economics structure, improvement energy efficiency, and implement policies and so on. We must do our best to realize the reduction, and we can do it.

Literature

Ang, JB (2009) “CO2 emissions, research and technology transfer in China”, ECOLOGICAL ECONOMICS, Vol. 68, pp. 2658-2665.

B.W. Ang (1994) “Decomposition of industrial energy decomposition: the energy intensity approach”, Energy Economics, Vol.16, pp. 163–174.

B.W. Ang (2004) “Decomposition analysis for policymaking in energy: which is the preferred method? ”, Energy Policy, Vol. 32, pp. 1131–1139.

B.W. Ang (2005) “The LMDI approach to decomposition analysis: a practical guide”, Energy Policy, Vol. 33, pp. 867–871.

Boqiang Lin, Chuangwang Sun (2010) “Evaluating carbon dioxide emissions in international trade of China” , Energy Policy, Vol.38, pp.613-621.

Can Wang, Jining Chen, Ji Zou (2005) “Decomposition of energy-related CO2 emission in China: 1957-2000” , Energy, Vol. 30, pp.73-83.

China National Development and Reform Commission (2007) "China's climate change national legislation."

China National Development and Reform Commission (2004) "long-term conservation planning

expertise."
China National Development and Reform Commission (2007) "11th Five-Year Plan Energy Development."
China National Development and Reform Commission (2007) "Comprehensive plan for energy conservation to reduce emissions."
China National Development and Reform Commission (2007) "long-term renewable energy development plan."
Christopher L. Weber, Glen P. Peters, Dabo Guan, Klaus Hubacek (2008) “The contribution of Chinese exports to climate change”, Energy Policy , Vol.36, pp.3572-3577.
Fan, Y; Liang, QM; Wei, YM; Okada, N (2007) “A model for China's energy requirements and CO2 emissions analysis” , Environmental Modelling & Software, Vol. 22, pp. 378-393.
Fan, Y., Liu, L.-C., Wu, G. Wei, Y.-M., (2007) “Changes in carbon intensity in China: empirical findings from 1980-2003”, Ecological Economics, Vol.62, pp.683-691.
GuoHong Wang, YunXia Wang, Tao Zhao (2008) “Analysis of interactions among the barriers to energy saving in China” , Energy Policy, Vol.36, pp.1879-1889.
Guan, D; Peters, GP; Weber, CL; Hubacek, K (2009) “Journey to world top emitter: An analysis of the driving forces of China's recent CO2 emissions surge” , Geophysical Research Letters, 36 Art No. L04709
Jalil, A, Mahmud, SF (2009) “Environment Kuznets curve for CO2 emissions: A cointegration analysis for China” , Energy Policy, Vol. 37, pp. 5167-5172.
Jin-Li Hu, Shih-Chuan Wang (2006) “Total-factor energy efficiency of regions in China”, Energy Policy, Vol. 34, pp. 3206-3217.
Kuishang Feng, Klaus Hubacek, Dabo Guan (2009) “Lifestyles, technology and CO2 emissions in China: A regional comparative analysis” , Ecological Economics, Vol. 69, pp.145-154.
Lan-Cui Liu, Ying Fan, Gang Wu, Yi-Ming Wei(2007) “Using LMDI method to analyze the change of China`s industrial CO2 emissions from fuel use: An empirical analysis” , Energy Policy, Vol. 35, pp.5892-5900.
Ming Zhang, Hailin Mu, Yahong Ning, Yongchen Song (2009) “Decomposition of energy-related CO2 emission over 1991-2006 in China” , Ecological Economics, Vol. 68, pp. 2122-2128.
Ming Zhang, Hailin Mu, Yadong Ning, Yongchen Song(2009) “ Decomposition of energy-related CO2 emission over 1991-2006 in China” , Ecological Economics , Vol.68, pp.2122-2128.
Peters, GP; Weber, CL; Guan, D; Hubacek, K (2007) “ China's growing CO2 emissions - A race between increasing consumption and efficiency gains” , Environmental Science & Technology, Vol. 41, pp. 5939-5944.
Qiao-Mei Liang, Ying Fan, Yi-Ming Wei (2007) “Multi-regional input-output model for regional energy requirements and CO2 emissions in China” , Energy Policy, Vol.35, pp.1685-1700.
Xiaoli Zhao, Chunbo Ma, Dongyue Hong (2010) “Why did China’s energy intensity increase during 1998-2006: Decomposition and policy analysis” , Energy Policy, Vol.38, pp.1379-1388.
Wei Yiming, Liu Lancui, Fanying et al. (2008) "China's energy report (2008)", China scientific publisher.
Wu, S. Kaneko and S. Matsuoka, (2005) “ Driving forces behind the stagnancy of China's energy-related CO_2 emissions, intensity change and scale change”, Energy Policy, Vol.33, pp. 319–335.

Wu, S. Kaneko and S. Matsuoka,(2006) “Dynamics of energy-related CO2 emissions in China during 1980 to 2002: the relative importance of energy supply-side and demand-side effects”, Energy Policy, Vol.34, pp. 3549–3572.
Yan, YF, Yang, LK (2010) “China's foreign trade and climate change: A case study of CO2 emissions” , Energy Policy, Vol. 38 , pp.350-356.
Zhang, M; Mu, HL; Ning, YD (2009) “Accounting for energy-related CO2 emission in China, 1991-2006” , Energy Policy, Vol. 37, pp.767-773.
Zhang Kunmin, Pan Jiahua, Cui Dapeng et al. (2009) " An Essay on low-carbon development " , China Environmental Science Publisher.

Global Warming Action of Taiwan's Semiconductor/TFT-LCD Industries: How Does Voluntary Agreement Work in the IT Industry?

Shih-Fang Lo

International Division,

Chung-Hua Institution for Economic Research, Taiwan

MAILING ADDRESS:

Rm. 531, 75 Chang-Hsing St.

Taipei 106, Taiwan.

TEL: +886-2-2735-6006 ext.531

FAX: +886-2-2739-0610

Email: shihfang.lo@cier.edu.tw

Current version: 2010/07/06

Global Warming Action of Taiwan's Semiconductor/TFT-LCD Industries: How Does Voluntary Agreement Work in the IT Industry?

Abstract

Voluntary agreements have been widely used in greenhouse gas (GHG) reduction policies because they offer more flexibility than direct regulation. However, this approach is often criticized for its effectiveness in developing countries, where the government's environmental regulatory framework is typically weak, and the firm's environmental awareness lags behind. By looking at the high global warming potential (GWP) gas reduction, this paper aims to understand the successful factors that make voluntary agreements more effective. We use Taiwan's semiconductor and TFT-LCD industries as a case study. When compared with their prosperous growth, the industries are proactive in GHG reduction by setting ambitious reduction goals that are far tighter than the 'business as usual' basis. We observed that the main driving forces were the pressures from environmental trade barriers, international industrial associations, and customers' green procurement policies upon Taiwanese IT industries.

Key words: voluntary agreement, semiconductor industry, TFT-LCD industry, high GWP gas emissions, PFC emissions

1. Introduction

The emissions of high global warming potential (GWP) greenhouse gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6), have been given more consideration by policy-makers since their incorporation into the commitments of the Kyoto Protocol. These gases have a more powerful greenhouse effect than CO_2 emissions. For example, a ton of HFCs can be equivalent to many thousands of tons of carbon dioxide over a 100-year period, as shown in Table 1. The growth of these high GWP gases has been affected by the developments taking place within industry. Initially, PFC emissions were predominantly a byproduct of primary aluminum production. Since the early 1980s, however, special solvent applications in semiconductor manufacturing have started to account for an increasingly large share of global PFC emissions, followed by the booming TFT-LCD (Thin Film Transistor-Liquid Crystal Display) industries (Olivier and Bakker, 2000). In terms of reduced emissions of non-CO_2 gases, high GWP greenhouse gases (GHG) can also contribute tremendously to climate change.

< Insert Table 1 around here >

Since applying a direct regulation to GHG emissions is difficult, voluntary agreements have been extensively deployed in climate change policy (Carraro & Egenhofer, 2003; Croci, 2003). The popularity of a voluntary agreement stems principally from the perception that it provides flexible and inexpensive management of environmental problems. Voluntary agreements can also improve welfare by generating more private-sector investment in pollution control before the public sector establishes stricter regulations. In industrialized countries, such an approach has become quite popular over the past two decades (OECD, 1999, 2003). However, little is known about whether voluntary agreements are likely to be effective in developing and transitioning countries, where local and federal environmental regulatory capacities are typically weak. A voluntary agreement policy is worthy of additional investigation in developing countries because their GHG emissions have grown dramatically in recent years.

As a developing country with a non-party status in relation to the Kyoto agreement, Taiwan is responding voluntarily to mitigate global warming and to implement 'no-regret' policies. Taiwan is now the world's major manufacturer and exporter of information technology (IT) products: it is the fourth largest in the semiconductor industry and the largest in the TFT-LCD industry. The booming of these two industries has been accompanied by the growth of related gases with high GWP. These industries use a number of gases classified as PFCs for both silicon etching and in the chamber cleaning process related to fabrication equipment.

Unlike conventional GHG reduction cases, which have undergone strenuous negotiations between the government and the relevant industries, the PFC emissions reduction programs in Taiwan have been quite smooth and effective. When compared to the prosperous industrial growth, the voluntary reduction goals are far tighter than the 'business as usual' goals, which are proactively set by the IT industry. This study, therefore, intends to better characterize the successful factors leading to voluntary agreements in developing countries. We take the high GWP gases as an example to investigate how Taiwan's IT industry reacts to the global warming issue.

The remainder of this paper is organized as follows: Section 2 broadly depicts Taiwan's semiconductor and TFT-LCD industries; Section 3 introduces the international/domestic GHG reduction activities; Section 4 investigates the successful factors within the voluntary agreement and the pressures confronting the industries; and Section 5 concludes the paper.

2. The Semiconductor and TFT-LCD Industries in Taiwan

Taiwan is presently the 17th largest economy in the world, the 14th largest exporter and the 16th largest importer. The country has gradually developed its high-tech industries over the past two decades and currently has the fourth largest information hardware and semiconductor industries in the world. Given that the semiconductor and TFT-LCDs industries were seen as critical to fueling the country's economic growth, the government of Taiwan officially announced its national goal: a 'Two Trillion and Twin Star Industries Development Plan' (Department of Industrial Technology, MOEA, 2004). The goal was to promote the country's Twin Star Industries, namely, semiconductors and flat panel displays (FPDs), to achieve annual sales of NT$2 trillion (approximately US$57 billion, with $45 billion for semiconductors, and $12 billion for FPDs) by 2006. The market scale of TFT-LCDs is about 70% of that for FPDs. In this section, we briefly introduce the background of Taiwan's semiconductor and TFT-LCD industries.

2.1 Taiwan's semiconductor industry

Products associated with computers and integrated circuits, such as PCs, electronic consumer products, notebooks, and their key components, have collectively defined the electronics high-tech industry. The global market demand for IC chips and semiconductors has grown with the demand for these IC products. The semiconductor industry can be roughly categorized into IC design, IC fabrication, IC packaging and testing. The IC fabrication industry uses relatively large types of chemicals because its manufacturing process is relatively complicated. Therefore, this industry is the major source of emissions from the overall semiconductor industry. Semiconductor manufacturing is a highly competitive industry. To compete globally, companies in that industry require large amounts of capital investment either for establishing new fabs, or for new designs and processes in the current fabs.

Reducing costs and increasing manufacturing productivity are the key factors to remaining sufficiently profitable.

Taiwan is the fourth largest economy in terms of IC manufacturing in the world. Figure 1 depicts the growing trend in Taiwan's semiconductor industry, and its sub-category industries (ITRI, 2006). With its total revenue expected to rise to over US$60 billion by 2010, the semiconductor industry in Taiwan has demonstrated astonishing growth. The revenue from IC fabrication accounts for about a half of its total revenue. The Taiwan Semiconductor Industry Association (TSIA) was founded in November 1996 to meet the growing demand for industrial activities and to promote cooperation with and the development of Taiwan's local semiconductor industry. TSIA has played an important role in reducing PFC emissions, which will be discussed in a later section.

< Insert Figure 1 around here >

2.2 Taiwan's TFT-LCD industry

By gradually replacing cathode ray tube (CRT) displays, flat panel displays (FPDs) are revolutionizing the way people look at computers. The FPDs provide greater brightness, contrast and environmental benefits, such as very low emission fields, no magnetic field, and reduced power consumption. As for the application of these FPDs, the thin film transistor liquid crystal display (TFT-LCD) is the most promising. TFT-LCDs are now widely used in PC applications, such as in notebook and desktop monitors; in mobile devices, such as personal data assistants (PDAs), cell-phones, and e-books; in car applications for navigation aids, safe-driving support, and rear-seat entertainment; and in home and office applications, such as TV, Internet terminals, and e-newspapers. Like the semiconductor industry, the TFT-LCD industry is highly capital-intensive. The industry requires large amounts of capital to purchase manufacturing equipment, high levels of technology to ensure the liquid crystal's stability and yield rate, and an abundant supply of labor for the final module assembly.

Taiwan now produces more than 40% of the world's supply of TFT-LCDs. In 2002, Taiwan overcame Japan to rank second in the world behind South Korea. Then, in 2004, Taiwan surpassed South Korea by producing 46% of the world's TFT-LCDs, becoming the largest supplier in the world. Figure 2 shows the growing trend in Taiwan's TFT-LCD industry (ITRI, 2006). In 2004, total revenues from the industry amounted to over $14 billion. This trend is expected to increase rapidly in response to the large demand for TFT-LCD-related devices. In addition, the large-sized panels account for the largest shares of total revenue. As the size of the LCD panel increases, larger inflows of capital are required for investment. For example, building a fifth-generation (panel size: 1100x1250 mm) TFT-LCD plant would cost more than US$1 billion; therefore, the continued investment of capital is critical to the ongoing success of the TFT-LCD industry.

< Insert Figure 2 around here >

3. GHG reduction activities

Even though PFCs and their related compounds are still an essential part of the semiconductor and TFT-LCD manufacturing processes, the associations and their member companies in Taiwan have worked aggressively for the past several years to reduce the use of PFCs and mitigate their environmental impacts. The international and domestic reduction activities of these two industries are introduced in the following section.

3.1 International voluntary reduction agreements

Since 1999, most PFC emissions from semiconductor manufacturing have been subject to a voluntary reduction goal established by members of the World Semiconductor Council (WSC). A concrete reduction goal for all members of the WSC has been established to limit PFC emissions to 10% below a base-year (typically 1995) level of emissions by 2010. The baseline years are slightly different for each of the five WSC associations. For the U.S. Semiconductor Industry Association (SIA), the Japan Electronic and Information Technology Industries Association (JEITA) and the European Semiconductor Industry Association (ESIA), the baseline year is 1995; for the Korean Semiconductor Industry Association (KSIA), the baseline year is 1997; and for the Taiwan Semiconductor Industry Association (TSIA), the baseline year is 1998* (called 1998 star), which represents the average emission values in 1997 and 1999. The baseline is set through negotiations between the WSC and each individual association. Since the development of Taiwan's semiconductor industry has taken place relatively later than other industrialized countries, the baseline was set to a later year.

In semiconductor manufacturing processes, dry etching and CVD (chemical vapor deposition) chamber cleaning are two major processes that use PFCs. As shown in Figure 3, PFC emissions recently increased, from 0.85 MMTCE (million metric tons carbon equivalent) in 1999 to 1.50 MMTCE in 2004. This increase was mainly due to the increase in product yields. The goal for Taiwan's semiconductor industry is to control the total reduction in PFCs to 0.66 MMTCE (the emission quantity for 1998 star). This reduction requires great efforts because production growth is forecast to continuously increase, as depicted in Figure 1.

< Insert Figure 3 around here >

Like the semiconductor industry, the TFT-LCD industry has also signed an international PFC reduction agreement. The World LCD Industry Cooperation Committee (WLICC) member associations from Japan, South Korea, and Taiwan

(LIREC/JEITA, the LCD Industries Research Committee in Japan; EALCD, the Environmental Association of LCDs in Korea; and TTLA, the Taiwan TFT-LCD Association) have committed themselves to voluntary activities to reduce the aggregate absolute emissions of PFCs from the TFT-LCD fabrication facilities to less than 0.82 MMTCE by the year 2010. This reduction goal will be applied among LIREC/JEITA, EALCD and TTLA, and the goals will be reviewed based on the latest progress as appropriate and necessary. The three parties have also agreed to a common countermeasure: a 100% installation rate for PFC abatement tools for 'new lines' (fabs designed since 2003).

Among the TFT-LCD manufacturing processes, dry etching and CVD chamber cleaning are two major processes that use PFCs. As shown in Figure 4, PFC emissions have increased rapidly with the industry's booming production in Taiwan, from 0.01 MMTCE in 1999 to 0.46 MMTCE in 2005. The goal for Taiwan's TFT-LCD industry is to control the overall reduction in PFCs to 0.27 MMTCE. The goal is to reduce the emissions constantly compared with 2003, which obviously requires great efforts because the world demand for TFT-LCD-related products will remain strong over the next few years.

< Insert Figure 4 around here >

3.2 Domestic voluntary reduction agreement

Besides the international voluntary reduction agreement, Taiwan's semiconductor and TFT-LCD industries have also reached a reduction agreement with the government. The TSIA signed a memorandum of understanding to cooperate in reducing PFC emissions with the Taiwan Environmental Protection Agency (EPA) in 2005. The TSIA agreed to use 1998 star as the basic reduction amount, and TSIA intends to reduce the total amount of PFC emissions to below the reduction baseline by 2010.

Furthermore, TSIA has also drawn up a GHG reduction roadmap, including a third party audit and verification program. TSIA's consultant, the Industrial Technology Research Institute (a non-profit R&D organization founded by the government) will provide consulting services to member companies.

The TTLA also signed a memorandum of understanding to reduce PFC emissions in cooperation with Taiwan's EPA in 2004, prior to TSIA. TTLA agreed to choose 2002 as the starting year for reducing PFC emissions and use the PFC emission intensity of 0.0335 TCE/m^2 substrate area as the reduction baseline. All member companies of the TTLA must install equipment that eliminates at least 90% of their total PFC emissions in new plants built after 2003, or in plants that have engaged in mass production since 2004. Differing from the semiconductor industry's total emissions reduction goal, the TFT-LCD industry sets its goal based on the emission intensity. This difference is because the industry is still rapidly growing, and controlling the PFC emission intensity is more likely to take into account both the economic and environmental aspects of the process.

Four major PFC emission reduction strategies and technologies have been adopted by Taiwan's semiconductor/TFT-LCD industries: (i) PFC emissions calculation: calculating annual PFC emissions and establishing a reduction strategy; (ii) Process optimization: optimizing the usage of PFCs inside the process chamber by source reduction, capture, and recycling; (iii) Scrubber installation: using effective abatement tools, known as a 'local scrubber,' to destroy the gas; (iv) Gas substitution: using substitute chemicals with less global warming effects.

4. Discussion

To date, the reduction strategies of Taiwan's semiconductor and TFT-LCD industries have primarily focused on domestic and international voluntary agreements.

Voluntary agreements are usually considered a valid policy because they encourage early action and are widely used in GHG reduction policies worldwide. There are several advantages for both the industries concerned and the government: (i) they decrease transaction and administrative costs because the two sides require shorter negotiation processes and less intensive monitoring; (ii) they increase information sharing; (iii) they enhance more cooperative relationships in terms of environmental policies; and (iv) they reduce abatement costs by providing flexibility in how standards are met (Segerson & Micelli, 1998; Bizer & Jülich, 1999).

However, voluntary approaches are criticized for being non-legally binding. Additionally, the targets that are often set are not very ambitious and are close to 'business as usual' (Croci, 2003). As for the cases of Taiwan's semiconductor/TFT-LCD industries, the voluntary reduction goals, whether by total quantity or intensity reduction, are far tighter than the 'business as usual' case. Compared to the forecasted rapid growth, the emission reduction goals are set to minus or zero increments. Therefore, it is worth investigating why the industries are willing to achieve these challenging reduction goals. Some critical observations are detailed in the following paragraphs.

4.1 Pressure from environmental trade barriers

Environmental trade barriers, by definition, are excessive or have stringent environmental regulatory standards that influence trade. Most regulations are imposed by the European Union, with the remainder being enforced by Japan, the United States, and the multilateral environmental agreements. Developing countries from South Asia, Africa, and the Asia-Pacific region are those that have been most affected (Oxley, 2003). As for the electrical and electronic products industry, environmental trade barriers are categorized by their large scope, such as the regulation of toxic substances, waste and recycling obligations, packaging/labeling requirements, and standards on energy efficiency/emission reductions, etc.

Compared to traditional industries, such as steel, chemicals, pulp and paper, etc., Taiwan’s semiconductor/TFT-LCD industries are more proactive in terms of GHG reduction activities because the two industries are export-oriented. The products and manufacturing processes are highly regulated by international standards. Any new international environmental regulations immediately exert great pressure on the industries. The environmentally sensitive attitude of Taiwan’s IT industries can be traced back to the early 1990s, when the Montreal Protocol controlled the emissions of CFCs and Halon. More recently, the industries have paid close attention to the new EU environmental directives, such as WEEE (Waste from Electrical and Electronic Equipment), RoHS (Restriction of Hazardous Substances), and EuP (Energy-using Products), in addition to the ratification of the Kyoto Protocol. The threat of possible trade barriers resulting from these regulations is their major concern.

4.2 Pressure from international industrial associations

The pressure exerted by international industrial associations also acts as a primary driver of abatement in the semiconductor/TFT-LCD industries. A commitment to the concrete PFC emissions cap is one of the requirements for the Taiwan association to join the WSC. Since the PFC emissions reduction program is not competitive, the WSC has established a reporting program for tracking and sharing PFC-related information on techniques and strategies. The members of the WSC are obligated to share relevant data on their PFC reduction programs through a working group that meets twice a year, and through the annual International Semiconductor Environment, Safety and Health (ISESH) conference.

Differing from energy saving activities that cover the whole of the production process, the reduction in PFCs can be more efficiently dealt with by installing the gas-destroying equipment at the end of the pipe, which is known as a local scrubber. Since the expenditure on the equipment is relatively low when compared to the total cost, the industries are more willing to expend resources on it. The TFT-LCD manufacturers in Taiwan have implemented local scrubbers providing a 90% destruction rate for production lines designed after 2003.

4.3 Pressure from green procurement

With the growth of environmental protection awareness, global companies are planning and incorporating a 'green supply chain' into their buying decisions. Companies have started collecting detailed environmental data on purchasing by making mandatory requirements for their suppliers. For example, SONY has asked its suppliers to provide the GHG emissions information to enforce green procurement. Firms that cannot respond to the stricter environment regulations may eventually fade out. As members of the global IT product supply chain, Taiwan's semiconductor/TFT-LCD industries are under pressure to survive. This pressure is completely reflected by their self-motivation to participate in the voluntary agreements to reduce their PFC emissions. Additionally, 'green production' is becoming a new indicator of a firm's international competitiveness.

5. Conclusions

Voluntary agreements have been widely used in GHG reduction policies because they provide more flexibility than direct regulation, while the responsibilities of those that generate emissions are not yet clear. These agreements also encourage businesses to take early action. However, this approach is criticized in terms of its effectiveness for developing countries, where the government's environmental regulations are typically weak, and the firm's environmental awareness lags behind. By looking at the high-GWP gas reduction targets, this paper aims to advance the understanding of the underlying driving forces to make the voluntary agreements more effective in developing countries. We have used Taiwan's semiconductor and TFT-LCD industries as a case study.

Although the successes of voluntary agreements have been widely discussed, such as the involvement of the industrial sector, public-private cooperation, or the underlying business culture, etc, the pressures that the industries themselves are facing has been discussed less frequently. In this study, we have observed that even in a non-affiliated country such as Taiwan, which, under the Kyoto climate change protocol, has no legal obligation to reduce its greenhouse emission gases, the IT industry has been proactive in GHG reduction, both internationally and domestically. The voluntary reduction goals have been set tighter than the 'business as usual' goals, when compared with the industry's future growth. The main driving force is the pressure exerted by environmental trade barriers, international industrial associations, and by customers' green procurement policies. The industries are willing to meet these challenging reduction goals because the pressures to reduce their emissions are closely related to their ability to survive the competition.

Despite the absence of legal restrictions, the pressure to survive has pushed Taiwan's IT industries to rethink their responsibilities with regard to global warming. Future research efforts that collect information and investigating cases in other developing countries could help scholars and policy-makers further understand the drivers of GHG reduction behavior, which in the end will support global climate policy-making.

References

Bizer, K. and Jülich, R., 1999, Voluntary agreements: trick or treat? *European Environment*, 9 (2), 59-66.

Carraro, C. and Egenhofer, C., 2003, *Firms, Governments and Climate Policy: Incentive-based Policies for Long-term Climate Change*, Cheltenham: Edward Elgar.

Croci, E., 2003, Voluntary agreements for CO_2 emissions reduction: evaluation and perspectives, *Energy & Environment*, 14(5), 663-676.

Segerson, K. and Micelli, T.J., 1998, Voluntary environmental agreements: good or bad news for the environment? *Journal of Environmental Economics and Management*, 36 (2), 109-130.

Olivier, J.G.J. and Bakker, J., 2000, Historical global emission trends of the Kyoto gases HFCs, PFCs and SF_6, Conference on SF_6 and the Environment: Emission Reduction Strategies, San Diego, USA.

Oxley, A., 2003, *European Unilateralism – Environmental Trade Barriers and the Rising Threat to Prosperity through Trade*, The Australian APEC Study Center.

Department of Industrial Technology, MOEA, Taipei, Taiwan, 2004, Available from http://www.st-pioneer.org.tw

ITRI (Industrial Technology Research Institute), 2006, *2006 Semiconductor Industry Yearbook*, Industrial Economic & Knowledge Center, Hsinchu, Taiwan.

ITRI (Industrial Technology Research Institute), 2006, *2006 Flat Panel Displays Industry Yearbook*, Industrial Economic & Knowledge Center, Hsinchu, Taiwan.

OECD (Organization for Economic Cooperation and Development), 1999, *Voluntary Approaches for Environmental Policy: An Assessment.* Paris, France: OECD Environment Directorate.

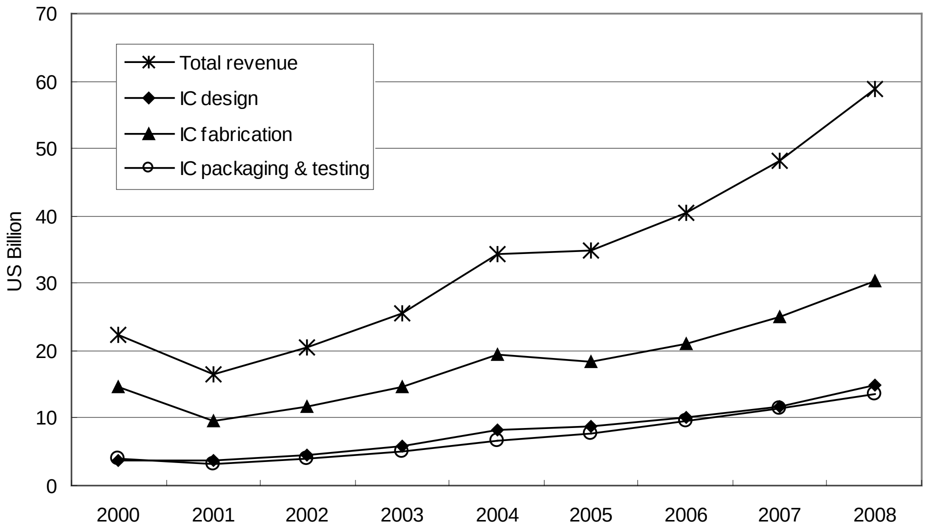
———, 2003, *Voluntary Approaches for Environmental Policy: Effectiveness, Efficiency and Usage in Policy Mixes.* Paris, France: OECD Environment Directorate.

Table 1. Global Warming Potential (GWP) Value

Greenhouse gas	Chemical formula	IPCC GWP
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbons	HFCs	150 ~ 11,700
Perfluorocarbons	PFCs	6,500 ~ 9,200
Sulphur hexafluoride	SF_6	23,900

Source: Intergovernmental Panel on Climate Change (IPCC) http://www.ipcc.ch/

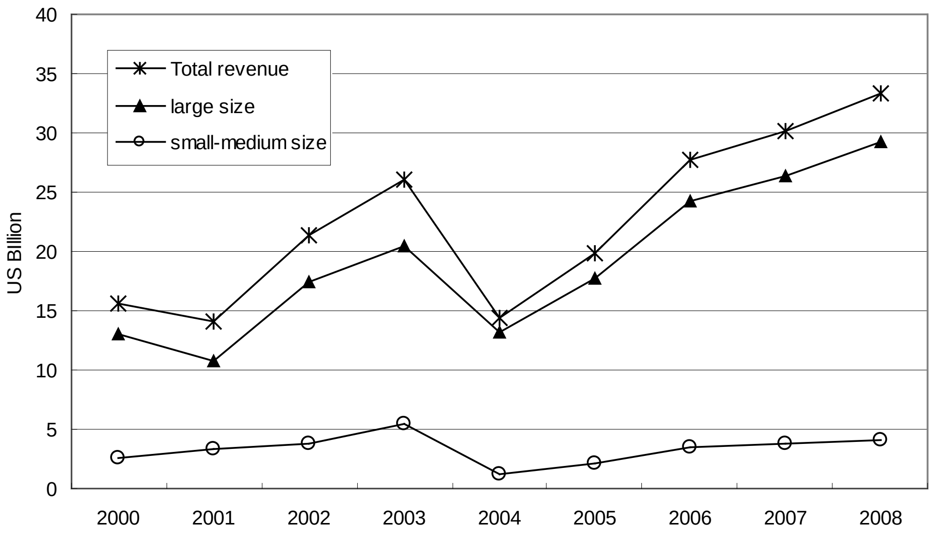
Note: GWP values are based on the effects of greenhouse gases over a 100-year time horizon



Source: *2006 Semiconductor Industry Yearbook* (2006)

Note: Data for 2007 and 2008 are forecasted.

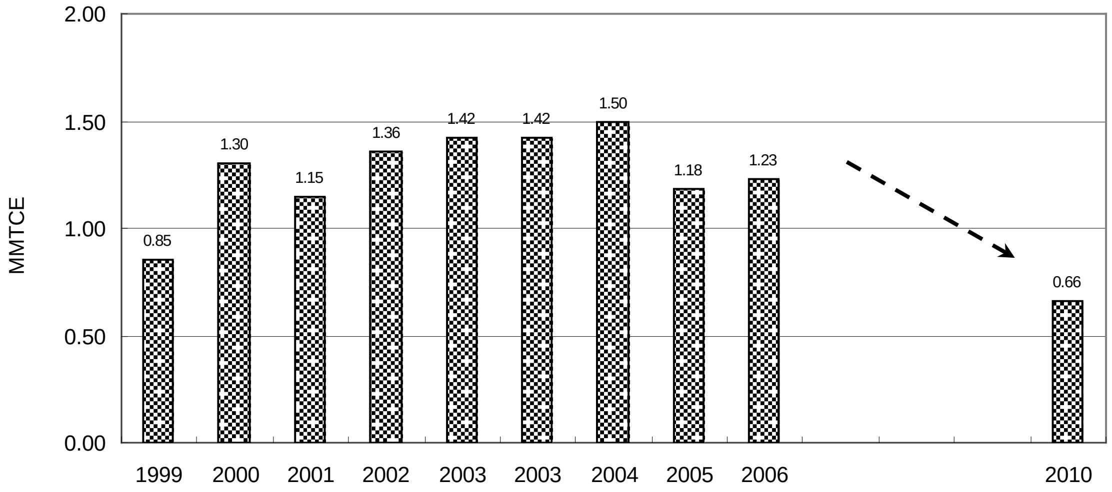
Figure 1. Product Revenue for Taiwan's Semiconductor Industry



Source: *2006 Flat Panel Displays Industry Yearbook* (2006)

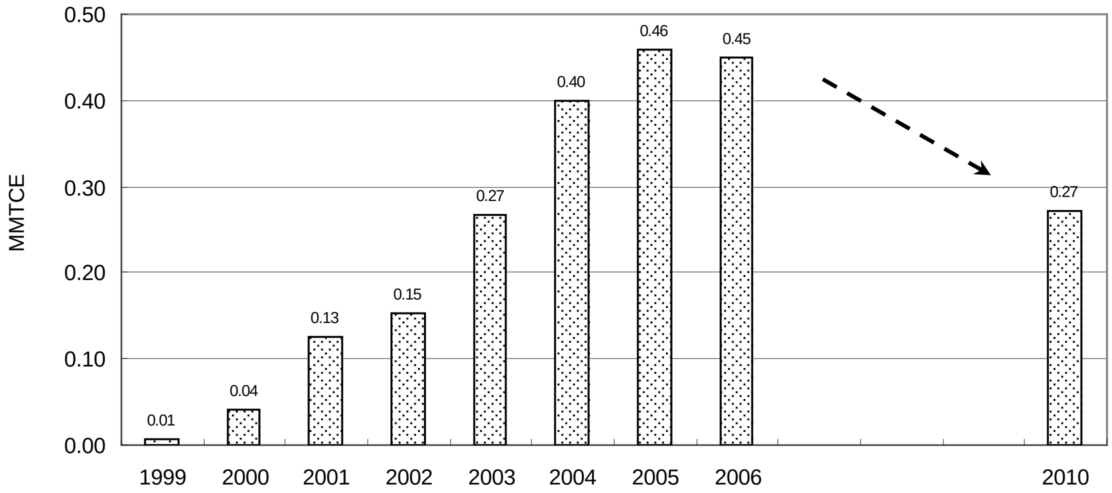
Note: Data for 2007 and 2008 are forecasted.

Figure 2. Product Revenue for Taiwan's TFT-LCD Industries



Note: MMTCE is the abbreviation for a million metric tons of carbon equivalent.

Figure 3. PFC Emission Trend and Reduction Target for the Semiconductor Industry in Taiwan



Note: MMTCE is the abbreviation for a million metric tons of carbon equivalent.

Figure 4. PFC Emission Trend and Reduction Target for the TFT-LCD Industry in Taiwan

Cost-benefit analysis for assessing CDM activities for energy technologies in Asian Countries by development of an integrated assessment

K. Tokimatsu[1,2], K. Okajima[3], A. Murata[2], N. Nomura[2], E. Endo[2]

1 The Institute of Applied Energy (IAE), 2 National Institute of Advanced Industrial Science and Technology (AIST), 3 Tsukuba University

1. Introduction

The Japanese government set a long-term target of cutting global green house gas (GHG) emissions by half from the current level by 2050 as a common goal for the entire world in the "Cool Earth 50". Large amount of energy-related carbon dioxide (CO_2) emission reduction, such as 60 to 80% and 25% is required as the long-term and the mid-term targets for Japan, respectively. The mid-term target for energy-related carbon dioxide (CO_2) emission reduction by 2020 in Japan is 25% from the level in 1990. Kyoto mechanism, such as CDM, might be indispensable to achieve such an ambitious challenge.

2. Research objectives

A background of this study aims to develop an integrated assessment (IA) to evaluate CDM projects for supply-side energy technologies in Asian countries in next few decades. By combining energy systems analysis models that provide macroscopic view of energy systems and life-cycle assessment models that analyze microscopic, potential amount of CDM credit anticipated from those activities will be discussed with their costs and benefits, in the light of the contribution of technology development to Japanese global environment policies.

This paper focuses on cost benefit analysis (CBA) of introducing energy supply technologies in the development of IA. We have two novel points for the CBA study. First point is that we choose fossil fueled large scale power plants as a case study for the CBA. Although numbers registered as CDM projects for energy supply technologies such as hydropower, wind power and biomass are growing recently, such large scale power plants had hardly been approved as CDM projects. Second point is that we especially focus on baseline issues and evaluation of environmental externality. These issues also had hardly treated in analysis CDM projects.

In order to analyze these issues, we applied following three models and analyses. One is lifecycle inventory analysis (named Energy Chain Multi-layered LCA model) to evaluate internal cost and emission inventories (e.g., CO2, SOx, NOx) for the target technologies. Next model is a power generation planning model of Chinese six major power grids (one of partial models of energy systems models named GOAL) to project baseline emissions factors of the inventories where the technologies are installed. The third model is a lifecycle impact assessment model (named LIME) to evaluate environmental external cost of local air pollution, transboundary acidification, and global warming caused by the emission. Moreover, in order to adopt LIME evaluating present-day impact in Japan to other Asian countries for the future, we used "income adjusted naive benefit transfer (BT)" by using income elasticity for the marginal willingness to pay (MWTP) in LIME. We derived the elasticity from social survey and statistical analysis. By combining these three models, social survey, and statistical analysis, we conducted CBA of projects to install the technologies.

3. Methods

3.1 Development of IA

The developed IA is consisted by integrating different two types of models, such as energy system models of Japan and Asia and life-cycle assessment models. Figure 1 illustrates schematic view of the IA. The start point of this IA is to use MARKAL model for Japan that provides energy-related CO_2 emissions reductions to estimate required CDM credits to achieve long-term radical CO2 emissions reductions in Japan. Then the GOAL model for Asia is deployed to evaluate potential amount of CDM credits in Asian countries especially China and India. These models are not used directory to the CBA. We conducted CBA of projects to install the technologies, by using the three models previously described (the power generation planning model, the Energy Chain Multi-layered LCA model, LIME), social survey, and statistical analysis,

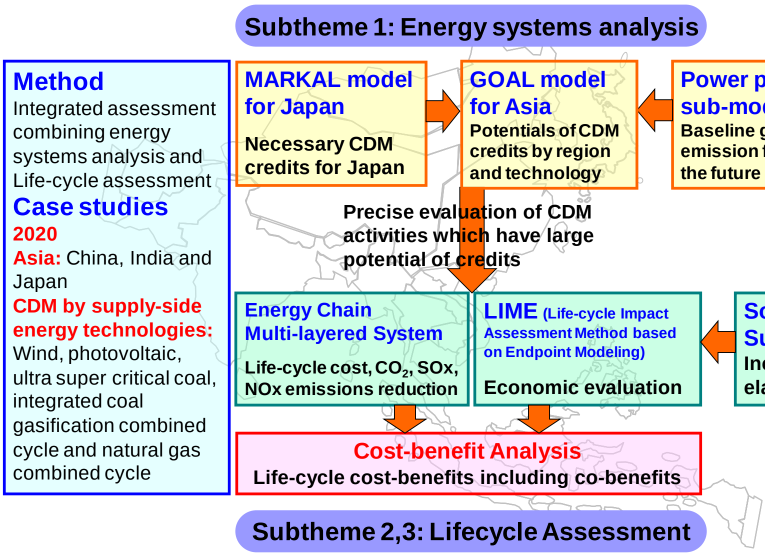


Figure 1 a developed integrated assessment (IA) by combining models of energy systems analysis with those of LCA

3.2 CBA

Project based CBA studies for energy technologies are evaluated by identifying differences between with and without the project. The differences in cost accounted in the CBA are followings as an example; incremental cost of install cost of the technologies as a cost, decrement cost for fuel energy saving and environmental impact reduction (e.g., SOx reduction) as a benefit. Then such a cost and benefit are discounted sum during the project lifetime to obtain cost-benefit ratio.

In this study, we evaluate the ratio to consider the project as perturbation. We assumed that a project is to installing a new pulverized coal fired power plant with ultra super critical (USC) in a so called “green field” in China. Hence, the baseline without the project is that of emission factor and average cost of the grid where the plant is located. By mean of “perturbation”, the emission factor and the average cost of the grid are not affected by installing the plant; hence the difference in cost and benefit are measured by the baseline.

4. Results

4.1 Scenario for internal cost and emissions

Figure 2 indicates both baseline emission factors (solid lines) from the power generation planning model and emission intensities of the technology (dotted lines) from the Energy Chain Multi-layered LCA model, for CO2 (top), SOx (middle), NOx (bottom), respectively. The assumed technology is the USC coal fired plant of 1 Giga Watt, 75 percent of plant availability, and 43 percent of thermal to electricity conversion efficiency. The "project" is assumed to construct it in Shanghai, where is in East of the six major grids. Hence, the baseline emission factors are those in the grid.

Emissions reductions are obtained until both baseline emission factor and emission intensities are crossed. CO2 reductions are obtained until some 10 years from the project starts; that from NOx reductions continues till the end of the project. We assumed strict emission control policy for SOx emission, leading the obtained baseline of SOx emission factor from the power generation planning model is lower than that from the technology.

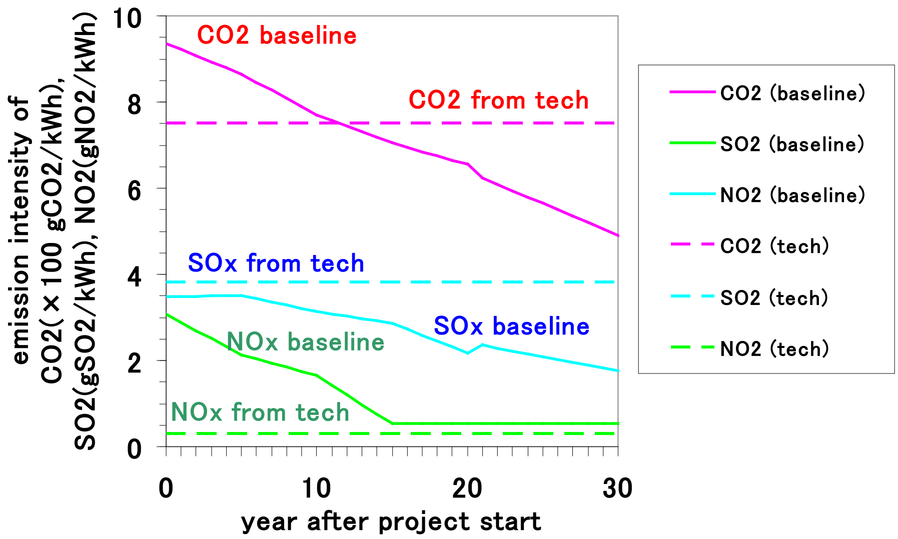


Figure 2 emissions intensity of the baseline and the installed technology for CO2, SOx, NOx. "baseline" means grid emission factors, "from tech" means emission intensities of the technology.

4.2 CBA

Those reductions are converted to monetary term by applying LIME evaluating present-day impact in Japan to other Asian countries for the future. CO2 emissions reductions mitigate global warming, reducing impacts on both human health and social assets. SOx and NOx emissions reductions mitigate local and transboundary air pollution, and acidification; reducing impacts on human health, social assets, and net primary productivity (NPP).

These endpoint impacts (e.g., human health, social assets, and NPP) are proportionally determined by population density, GDP, and potential NPP, respectively. Moreover, benefits in monetary terms gained by these reductions are decided by MWTP, whose major deciding factor is per capita income (GDP). Hence, we adjusted LIME by multiplying ratio between these values (e.g., population density, GDP, potential NPP) of target year in China and present day Japan. A review work on benefit transfer studies reveals that most of the transfer errors in the studies reviewed are less than 50 % for both of transfer among intra country and inter countries. We then adapted benefit transfer to MWTP in LIME. Income elasticity 0.9 is obtained from social survey and statistical analysis is applied to the BT.

Figure 3 illustrates results of dynamics of environmental benefit (A) from emissions reductions, difference of Cost of Electricity (B) of the technology from that of the baseline, its ratio as annual benefit per cost (A/B), and levelized benefit per cost (C1) with and without social rate of time preference (SRTP). The reason to continue growing (A) is due to MWTP by GDP increase. Discounted CBA is almost unity, meaning that this project is marginally suitable to normal commercial project and that might be compatible to CDM project. The CBA ratio is lower than that of other studies, because of the dynamic baseline.

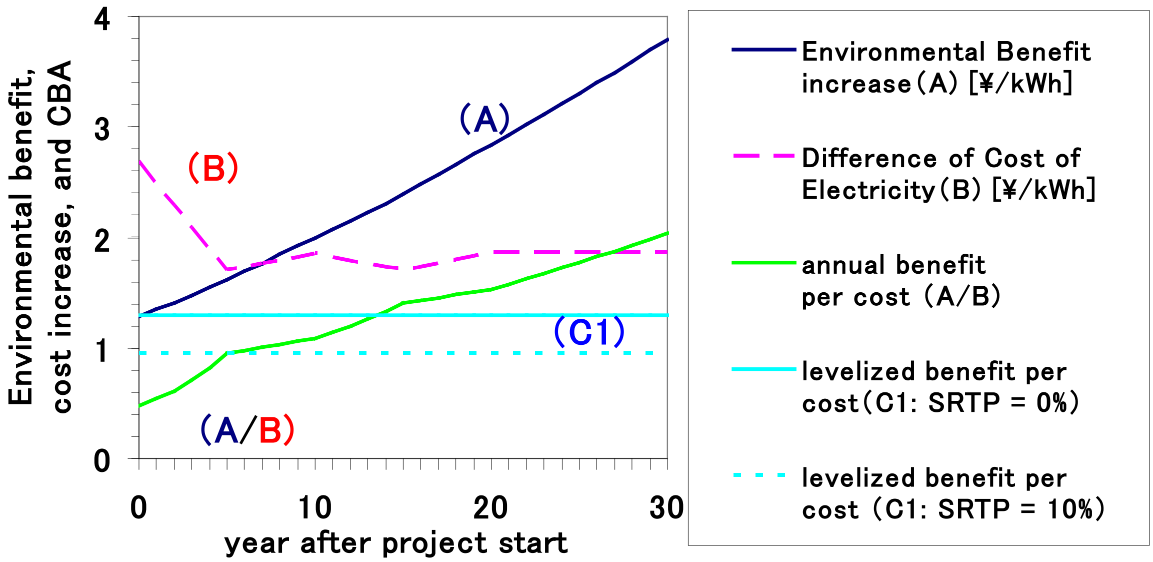


Figure 3 Cost-Benefit Analysis for introducing a new coal power plant of ultra super critical

4. Summary

By combining models of energy systems analysis and life-cycle assessment (LCA), we carried out simple example of CBA based on the idea of "perturbation". One of a main advancement of this CBA is to apply dynamic baselines from the energy models. Existing studies only assumes constant value of the baseline emissions in present day. The other advancement of this study is to apply lifecycle assessment for evaluating (reduction of) environmental external cost due to introduction of the power plant.

Acknowledgement

This research is supported by the "Global Environment Research Fund (B-074)" by the Ministry of the Environment, Japan.

Key Words

Cost Benefit Analysis, baseline issue, Supply-side energy technology, Energy systems Analysis, Life Cycle Assessment

Limited diffusion of LPG-Powered Vehicles in China

Vivian Leung

Abstract

Autogas (LPG when used as an alternative automotive fuel) out-performs gasoline and diesel in terms of SO_x, NO_x, particulate matters and CO_2 emissions. China has been keen to promote LPG-powered Vehicles (LPGV) since late 1990s but LPGV diffusion in China has been very slow. This study shows regulations mandating taxis to switch to LPGV were very effective in creating a niche market for LPGV in a few cities in China. However, strong regulations could not guarantee success. The biggest problem in the LPGV development in China during late 1990s – 2000s was a lack of policy coherence between the central and local governments. The central government, by imposing a very low fuel duty on gasoline and diesel, left very little room for local governments to enhance the price advantage of Autogas, which became the root of many problems concerning LPGV development in China. Maintenance costs of LPGV in China were high due to immature technology and lack of quality control. Fuel savings from using Autogas were not big enough to cover for the inconvenience in using Autogas and the high maintenance costs of LPGV, leading to many bi-fuel LPGV in Shanghai opted to run on gasoline instead of Autogas. During mid 2000s, in order to put domestic inflation under control, the central government exerted pressure to suppress price increase of gasoline and diesel. This tipped the balance of Autogas and gasoline, delivering a serious blow to the LPGV development in China.

Keywords: LPG Vehicles, Bi-fuel LPG Vehicles, policy coherence

1 Introduction

Liquefied Petroleum Gases (LPG) is predominantly propane and butane, derived as a by-product either from crude oil refining or from natural gas / oil production, commonly used as a domestic fuel for cooking and heating.

When LPG is used as an automotive fuel, it is often called "Autogas[1]". Autogas outperforms gasoline and diesel in terms of SO_x, NO_x, particulate matters and CO_2 emissions[2]. Autogas is a widely used and accepted alternative automotive fuel in use in the world today. As of 2007, there were over 13 million Autogas vehicles in

1 "Autogas" is LPG but when referring to pricing policy / price differential with gasoline, it is better to use the term "Autogas" as it is not uncommon for a country to impose different duties on LPG for domestic use, LPG for petrochemical use, and LPG for automotive use

2 source from Japan LP Gas Association

use around the world, with Korea, Turkey, Poland and Japan being the world's top four in terms of Autogas consumption[3].

China has been keen to develop alternative fuel vehicles. In 1997, China launched a "Clean Air – Clean Auto Act Program" by which 12 model cities[4] were chosen to conduct pilot projects on LPG-powered vehicles (LPGV) and Compressed-Natural-Gas-powered vehicles (CNGV). Interestingly, around the same period of time, LPG was legalized in Turkey as a transportation fuel, and by now Turkey has already become the world's number 2 in terms of Autogas consumption. Judging from the fact that a) both China and Turkey brought in LPGV around the same period of time; b) the world's top Autogas users – Korea and Japan – are China's close neighbors; and c) Hong Kong successfully switched all diesel-powered taxis to LPG-powered taxis during early 2000s; one would expect a comparable progress to be found in China. The data, however, are telling a different story. Table 1 gives a brief summary of the LPGV development in Korea, Turkey and China.

Table 1 LPGV development in Korea, Turkey & China

	Korea		*Turkey*		*China*	
	2004	*2009*	*2004*	*2009*	*2004*	*2007*
No. of LPGV (million units)	1.8	2.4	1.2	2.4	0.114	Below 0.08
Total No. of vehicles (million units)	14.9	17.3	10	14.3	27	44
% of LPGV in vehicle fleet	12%	13.8%	12%	16.8%	0.4%	Below 0.2%

Source:
Data for Korea from E1 Corp., 2009, World LP Gas Association
Data for Turkey from Karamangil 2007, World LP Gas Association
Data for China from China Automotive Industry Yearbook 2005 p182 / 2008 p.270, China Statistical Yearbook 2008, p621. "Total number of vehicles" in China refers to "civil vehicles" only.

This paper examines why diffusion of LPGV has been slow in China during late 1990s to late 2000s by comparing the public policies adopted in Hong Kong and two other cities in China - Shanghai and Guangzhou. It should be noted that although Hong Kong was returned to China in 1997, her administration and economic framework is still very different from that of mainland China. As these elements are important in the analysis of this study, "China" in this paper does not include Hong Kong.

The rest of the paper proceeds as follows. Section 2 discusses the characteristics of LPGV and the arguments calling for government interventions. Section 3 gives an overview on LPGV development in Hong Kong, Shanghai and Guangzhou. Section 4 discusses the problems of LPGV development in China. Section 5 summarizes the historical factors affecting the policies taken by Hong Kong and China. Section 6 gives the conclusion.

2 LPGV and Government Interventions

3 source from World LP Gas Association

4 Beijing, Shanghai, Tianjin, Chongqing, Harbin, Changchun, Xian, Urumqi, Sichuan mid area, Guangzhou, Shenzhen, Hainan

LPG-POWERED VEHICLES

LPGV is a proven technology, having a history of over 30 years. In most places, an existing conventional-fuel (gasoline or diesel) vehicle is converted to run on LPG by installing a separate fuel system that allows the vehicle to switch between the conventional fuel and Autogas, hence the name "Bi-fuel LPG vehicles". For mainly technical reasons, most light-duty vehicle conversions involve gasoline-powered engines, which are particularly well-suited to run on LPG. Heavy-duty vehicles with diesel engines converted to run on LPG are not as common because cost of conversion is much higher. Conversions are typically done by specialist auto-shops, using standardized kits involving a parallel fuel system and tank. The LPG fuel tank is usually installed in the boot / trunk.

Cost of conversion depends on the sophistication and quality of the equipment installed and local labor costs, it ranges from US$500 in developing countries to US$3,000 in the USA. Some large multinational Original-Equipment-Manufacturer (OEM) vehicle manufacturers have become involved in the development, design and manufacture of dedicated LPGV (vehicles running on LPG only). The premium for a light-duty OEM LPGV is typically at least US$1,000. Other than being more expensive, LPGV have certain disadvantages:

- Number of Autogas fueling stations is less than that of conventional fuels.
- As LPG is lighter than conventional fuels, a bigger tank is required to achieve the same overall driving range
- Loss of boot/ trunk space
- The weight of the LPG fuel tank may lead to a marginal loss in acceleration and speed
- Choices of OEM LPGV models are limited

GOVERNMENT INTERVENTIONS

Development of alternative fuel vehicles faces two fundamental problems. First, low-emission is a consumer externality. The low-emission alternative fuel vehicles have to compete with gasoline vehicles by price and performance. To be price-competitive during the infant stage is difficult due to increasing returns of scale of gasoline vehicles. Second, development of alternative fuel vehicles requires a simultaneous development of fuel supply infrastructure. Unfortunately, entrepreneurs are unlikely to be interested in investing in the fuel supply infrastructure when number of alternative fuel vehicles is still low. At the same time, car users would not be interested to buy the alternative fuel vehicles when number of fueling stations is small. It is a chicken-and-egg situation.

From above, one can appreciate why it is so hard for the automobile market to escape from the gasoline car technology. The success of the hybrid vehicles is partly due to the fact that a new fuel supply infrastructure is not required.

Urich (2000) points out in order to break free of historical conditions in carbon lock-in, the involvement of government is important because government policy can override market forces. Governmental intervention can create alternative incentive structures, or "rules of the game", to which firms have to adapt their strategies.

Köhler et al (2008) discuss the difficulties in increasing consumer demand for low-emission vehicles. The existence of a consumer externality means that consumers and the market get stuck in the existing gasoline / diesel technologies.

Köhler suggests three options to engineering a shift towards the use of low-emission vehicles: (1) create collective action via regulation; (2) use tax or subsidies to change the pay-offs; and (3) change consumer attitudes / preferences. Among the three options, (1) regulations are the most powerful and certain because regulators do not need to second-guess consumer choices. Regulations can be supported by (2) and (3).

While government intervention can play an important role, not all government intervention will lead to an improvement in efficiencies. Government failure arises when the government interventions actually lead to a reduction in social welfare, or when the interventions are conducted inefficiently (Grand, 1991; Winston, 2006). This study hypothesizes that it was government failure that led to the slow diffusion of LPGV in China during late 1990s to late 2000s.

3 Overview of LPGV Development in Shanghai, Hong Kong and Guangzhou

SHANGHAI

Among the three cities, Shanghai was the first to launch a large-scale scale LPGV development program. Effective from 1st Jan 1998, all new taxis were required to be fitted with either a dedicated LPG or a gasoline-LPG bi-fuel system. As reported in China Automotive Industry Yearbook (2001), it was Shanghai's plan to have all of the 40,000 units of taxis converted to LPGV by 2001-2002 and be served by about 135 Autogas fueling stations. Autogas consumption was expected to reach 260,000 tons per year after completion of the conversion program.

By end of 2001, about 75% of the taxis had been converted to LPGV (nearly all were bi-fuel LPGV). The percentage of LPGV taxis continued to rise then dropped sharply in 2006. By 2008, less than 5% of the taxis were LPGV. See Figure 1.

Figure 2 shows the changes in number of LPG taxis versus Autogas consumption in Shanghai. It can be seen that while the number of LPG taxis was increasing and stayed high until 2006, Autogas consumption was actually decreasing after 2001. This implies many of the LPGV were actually not using Autogas but gasoline. In June 2005, out of 38,709 LPGV taxis in Shanghai, less than 10,000 taxis were actually running on Autogas; and out of 107 fueling stations, about 20% have been closed down[5]. Due to strong objection from the taxis operators, the government finally abolished the regulation for new taxis to be equipped with either a dedicated or bi-fuel LPG system in early 2006.

5 from http://www.96822.com/dz-news/dz-yuekan/2005/2005-10/2005-10-08.htm (accessed Jan 01, 2010)

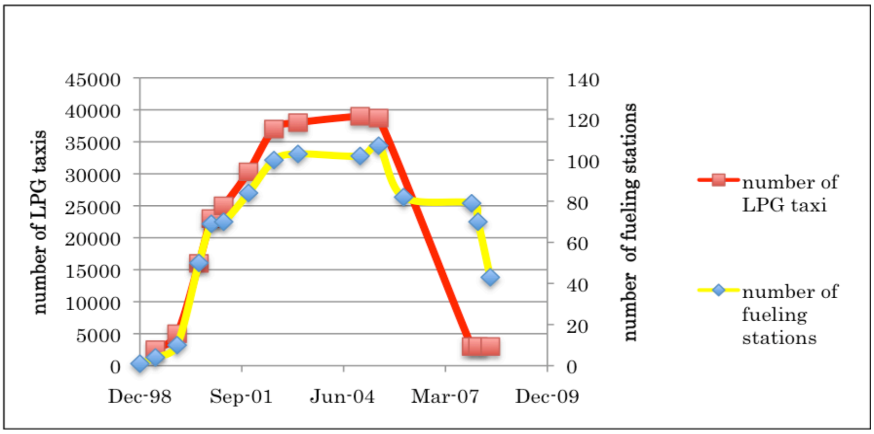


Figure 1 Change in number of LPG taxis and LPG fueling stations in Shanghai, 1998-2009

Source: Pang & Sun (2001); State Steering Group on Clear Car Act Project (2002); China Automobile Yearbook (2005); and news reported on internet

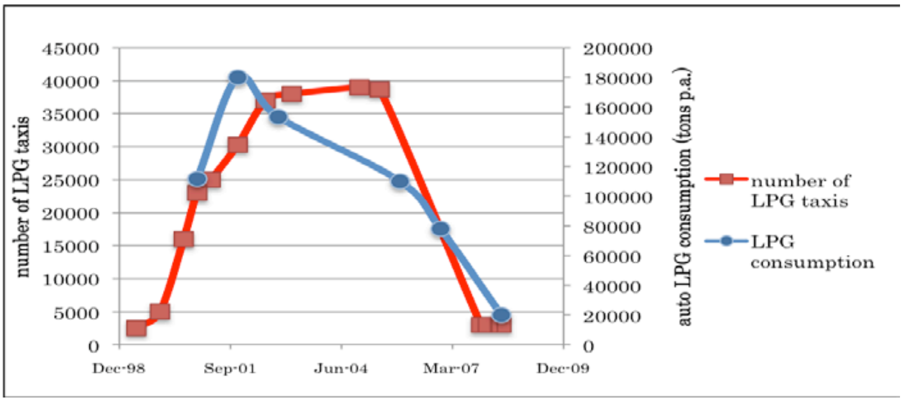


Figure 2 Changes in number of LPG taxis and Autogas consumption in Shanghai, 1998-2009

Source: Pang & Sun (2001); State Steering Group on Clear Car Act Project (2002); China Automobile Yearbook (2005); Shi (2003) and news reported on internet

HONG KONG

As opposed to taxis in China running on gasoline, taxis in Hong Kong were used to run on diesel. Due to the worsening air quality, the government passed a regulation banning import of diesel taxes effective from August 1st, 2001 (import of gasoline taxis is allowed but due to the huge price advantage of Autogas, this ban effectively drives all taxis to LPGV); and at the same time launched a subsidy incentive program[6] with a view to convert all of the 18,000 units of taxis to LPGV by 2006 (this target was reached in 2003).

As the LPGV conversion program for taxis was progressing smoothly, in 2002,

6 An incentive program was opened from August 8, 2000 to December 31, 2003 by which eligible diesel taxi owners who replaced their diesel taxis with LPG taxis could apply for a one-off grant of HKD40, 000 (~USD5,128).

a new subsidy incentive program[7] was launched targeting the public light buses (PLB)[8] on a voluntary basis. It is voluntary because import of diesel PLB remains legal.

It should be noted that the LPG-taxis and LPG-PLBs in Hong Kong are not "bi-fueled" nor "converted". They are brand new OEM dedicated LPGVs, mainly imported from Japan, made by Toyota and Nissan.

Figure 3 summarizes the outcome of the LPGV development in Hong Kong. As of 2008, 100% of taxis and over 60% of the PLBs in Hong Kong are running on Autogas, and there are 58 Autogas fueling stations including 12 large-scale "Dedicated Autogas Fueling Stations".

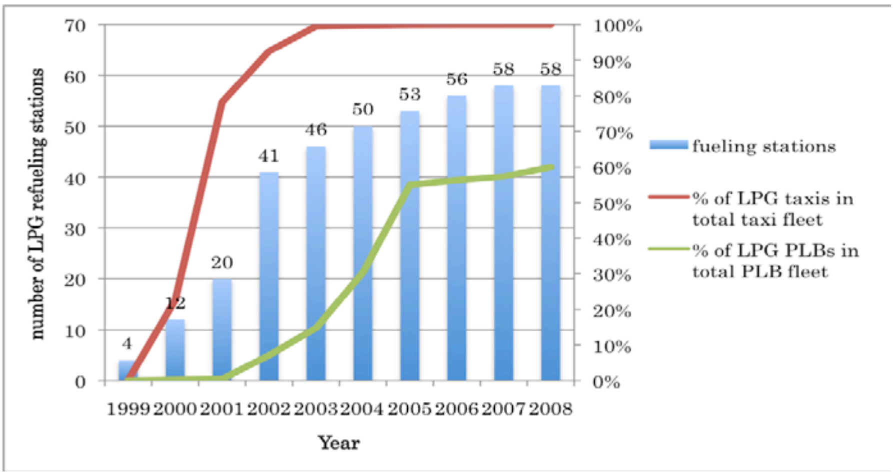


Figure 3 Change in number of LPG fueling stations and % of LPG taxis and LPG Public Light Buses (PLB) in Hong Kong, 1999-2008
Source: Hong Kong Government, Annual Transport Digest 1999-2008

GUANGZHOU

In 1999, Guangzhou city government announced a plan to convert all taxis and public buses to LPGV plus constructing 50 LPG fuelling stations by year 2001. The conversion program was not successful[9].

By 2003, nearly all taxis in Hong Kong had been replaced by LPGV. Seeing the encouraging development in Hong Kong on one hand and the worsening air quality in Guangzhou on the other hand, in June 2003, Guangzhou City Transport Committee announced a new plan to have all public buses and taxis converted to LPGV in 3 years'

7 An incentive program for diesel public light bus (PLB) was launched in 2002. PLB owners who replaced their diesel PLBs with LPG PLBs can apply for a one-off grant of HKD60,000 (~USD7,692). The deadlines for application were end of 2004 for diesel PLBs aged 10 years or above and end of 2005 for diesel PLBs aged below 10 years at the time of de-registration.

8 Public light buses in Hong Kong are 16-seat coaster, excl. driver. Brief specifications available at http://www.toyota.com.hk/cars/new_cars/coaster_lpg/index.asp (accessed Jan 1, 2010)

9 During 1999 to early 2003, there were a total of 599 buses and 6249 taxis converted to bi-fuel LPGV but Autogas consumption in 2003 was only about 10 tons per day9 (Chen, 2006). Also, the number of Autogas fueling stations reduced from six in 2000 to five in 2003.

time. The government also planned to have 5 new Autogas fueling stations completed in 2003, 23 in 2004, and to have a total of 52 Autogas fueling stations serving the LPGV fleet in Guangzhou by end of 2005[10]. Furthermore, instead of converting to LPGV from half run-down engines, the older buses were to be replaced by new dedicated LPGV, and the newer buses were to have the diesel engines replaced by new dedicated LPG engines.

Figure 4 shows the changes in percentage of LPG taxis and number of LPG fueling stations in Guangzhou during 2003 – 2009. By end 2006, nearly 100% of the taxis (16,000) and 80% of the public buses (6400 out of 8000) have been converted to LPGV. While the vehicle conversion was pretty much in line with the government's original plan, progress for the establishment of fueling stations was not as satisfactory. By end of 2005, instead of having 52 stations as wished, there were only 23 (Chen, 2006). This was increased to 32 by June 2009 (Gong, 2009).

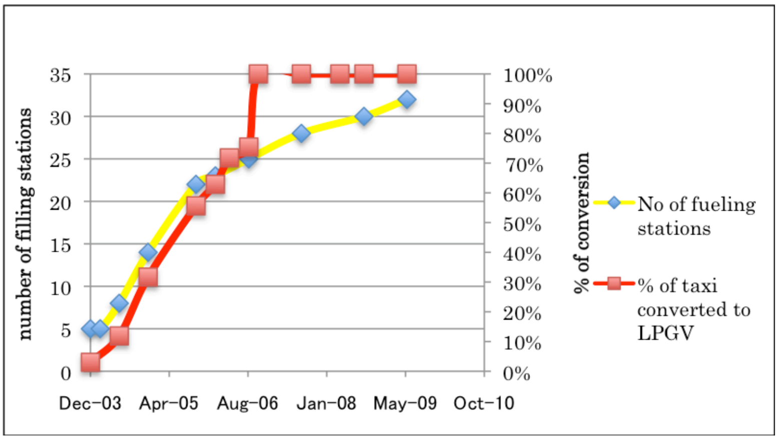


Figure 4 Changes in % of taxis converted to LPG taxis and number of LPG fueling stations in Guangzhou, 2003-2009

Source: data compiled from Chen (2006), Gong (2009) and news reported on internet

In Nov 2006, Guangzhou passed the assessment and was honored the "National Model City for Environmental Protection"[11]. This seems to show the LPGV development program in Guangzhou has been a success; unfortunately, the participating agents did not share the same optimistic view. A negative sentiment against the LPGV development was developing in Guangzhou in late 2000s. The public bus companies claimed, as of early 2008, they had accumulated more than 2 billion CNY extra expenses in relation to the LPGV program (including cost of conversion, extra operating and maintenance expenses). This led to substantial losses and cash flow problems to the public bus companies[12]. In Jan 2008, Guangzhou No. 1 Bus Company disregarded the government's directives by procuring 30 diesel-hybrid buses instead of LPG-buses.

10 from http://www.southcn.com/news/gdnews/areapaper/200310130715.htm (accessed Dec 31, 2009)

11 At the time of the award, only 63 cities and 5 townships passed the assessment and received the same honor, among a total of 657 cities. Furthermore, out of those honored cities/ townships, Guangzhou has the highest GDP, the biggest built-up area, the largest number of industrial enterprises, and the highest urbanization rate (from http://www.ce.cn/cysc/hb/gdxw/200702/02/t20070202_10296157.shtml, accessed Dec 31, 2009)

12 reported by http://news.52bus.com/2009/0113/article_6107.html (accessed Dec 29, 2009)

The public bus companies were not the only losers in Guangzhou. According to Gong (2009), a total of 400 million CNY have been granted by Guangzhou government to the Autogas fueling station operators to compensate for their trading losses by having to sell Autogas below import costs. As the compensation would only cover for 80% of the difference between the government dictated retailing price and LPG import costs, Autogas fueling stations had to bear the remaining 20% trading losses plus losses on operating costs (Zhang, 2009).

Due to the negative press and financial burden borne by both the public and private sectors, Guangzhou to some extent became a negative example rather than a role model for the development of LPGV for other cities in China.

4 Problems of LPGV development in China

According to Köhler et al (2008), regulations are the most powerful option to increase the consumer demand for low-emissions vehicles. Imposing regulation on taxis mandating their switch to LPGV was exactly the route taken by Hong Kong, Shanghai and Guangzhou[13], see Table 2. Why did all three cities target at taxis? It is because 1) taxis are running at very high mileage (300-500km per day is not uncommon) which makes taxis more responsive to fuel savings than ordinary private vehicles; 2) for most of the time, taxis are running in downtown areas where the air quality is often poor due to heavy traffic; 3) taxis can provide a niche market for the development of LPGV and the Autogas supply infrastructure; and 4) taxi being a public transport and therefore any preferential policies that make taxis, rather than private cars, use a cheaper but cleaner fuel should be better received by the public.

Table 2 Regulations adopted by Hong Kong, Shanghai and Guangzhou

Hong Kong	***Shanghai***	***Guangzhou***
No diesel taxis could be imported into Hong Kong from August 1st, 2001.	All new taxis are to be fitted with either a dedicated LPG or a gasoline-LPG bi-fuel system, effective from 1st Jan 1998.	In 2003, the city government strongly requested transportation companies to convert all of their taxi / bus fleets to LPGV within 3 years.

The regulations proved to be very effective because within a few years' time, all of the three cities have nearly all of the taxis converted to LPGVs. Why then did the LPGV program work in Hong Kong but not quite in China?

The problems with the LPGV development in China lie with the following:

1) Tax and subsidies system failed to widen the price advantage of using Autogas
2) Autogas price control mechanisms were good for car users but bad for Autogas fueling stations
3) Immature technology and poor quality control led to high maintenance costs of LPGV
4) Existence of a loophole in the LPGV regulations (a side effect of the bi-fuel system)
5) Polices in Guangzhou failed to evolve with time

(1) TAX & SUBSIDIES SYSTEM FAILED TO WIDEN THE PRICE ADVANTAGE OF

13 In Guangzhou, the strong "request" from the government was as powerful as official regulations

USING AUTOGAS

ULTRA LOW FUEL DUTIES ON GASOLINE MADE ADVANTAGE OF AUTOGAS MARGINAL

The fuel duties were as high as 40% of the final retailing price in Hong Kong; but just about 3% in China, see Table 3. While heavy fuel duties are imposed on gasoline but none on Autogas in Hong Kong, fuel duties for gasoline in China were a mere CNY 0.2 per liter[14]. As a result, despite no fuel duties were charged on Autogas, the price advantage for Autogas was very marginal.

Table 3 Comparison of Retailing Price and Fuel Duties of Gasoline in Hong Kong and Beijing, effective Oct, 2008

City	*Type of gasoline*	*Retailing Price (per liter)*	*Fuel duties (per liter)*	*% of fuel duties in retailing price*
Hong Kong[15]	Caltex Unleaded Gold	HK$ 15.2	HK$6.06	40%
Beijing[16]	93#	CNY 6.37 (~HK$ 7.27)	CNY0.2 (~HK$ 0.22)	3.1%

SUBSIDIES DECLINING WHILE CONVERSION COSTS WERE INCREASEING

One may expect cost of LPG conversion kit getting cheaper as time passes. In reality, it went up due to more stringent emission standards being imposed on vehicles. LPG conversion technology[17] has evolved through four generations, with newer and better technology continues to come.

- 1st generation - Mechanically-controlled, Open Loop LPG system, suitable for carburetor engine
- 2nd generation – Electronically-controlled, Close Loop, single point injection LPG system, suitable for early Electronic Fuel Injection (EFI) gasoline engine
- 3rd generation - Multipoint injection LPG system
- 4th generation - Multipoint sequential injection LPG system

As conversion technology advances, cost of conversion went up from about CNY3,000 to as much as CNY8,000[18]. In 2001, when China banned carburetor engines and required all new gasoline vehicles to be equipped with Electric Fuel Injection (EFI) engines and catalytic converters, cost of LPG conversion jumped up immediately to CNY5, 000- 6, 500 level. For environmental protection, it is an improvement to abolish carburetor engines and put the latest LPG conversion technology into use. The problem, however, is that the local government in most cities failed to respond to this increase in conversion costs. As a result, when conversion costs were getting higher, car users (except Shanghai & Guangzhou) became less keen to switch to LPGV.

14 Fuel duties for gasoline and diesel have been increased to 1.0CNY/L and 0.8CNY/L effective from 1st Jan 2009.

15 data from http://news.xinhuanet.com/fortune/2008-10/22/content_10230998.htm, accessed Dec 27, 2009

16 data from http://finance.jrj.com.cn/focus/8thcpyj/index.shtml, accessed Dec 27, 2009

17 For explanations on different types of conversion system, see Karamangil (2006) or http://www.go-lpg.co.uk/which_conversion.html (accessed Jan 01, 2010)

18 from http://www.gmw.cn/CONTENT/2008-02/20/content_736666.htm; http://sy.bendibao.com/news/200872/content25611.asp; http://news.sina.com.cn/o/2005-10-27/06267278956s.shtml; (accessed Jan 01, 2010)

MARGINAL ADVANTAGE OF AUTOGAS FAILED TO COVER HIGH RUNNING COSTS

High conversion cost, however, was not an obstacle for Shanghai and Guangzhou as it was compulsory for taxis there to switch to LPGV no matter they liked it or not. However, the high running costs sometimes caused LPGV to continue using gasoline, instead of the cleaner Autogas. Running costs were high due to: 1) number of fueling stations was small; and 2) maintenance costs of LPGV were high (more details in later section).

When number of fueling stations is small, taxi drivers have to drive a longer distance and incur extra waiting time to get Autogas refuel, which increases their running costs in using Autogas. The reason that the number of fueling stations was small[19] was again due to price advantage of Autogas being too small. Seeing the small price advantage of Autogas, the entrepreneurs expect demand for Autogas would not be high, hence not keen in investing in the Autogas supply sector.

NO INCENTIVES FOR CAR USERS TO PROCURE OEM DEDICATED LPGV

OEM dedicated LPGV have better performance[20] and are therefore preferred by both the local and central governments. However, no preferential financial support was provided for the procurement of OEM dedicated LPGV. Not only that OEM dedicated LPGV carries a premium of about CNY11, 000[21], dedicated LPGV has an added disadvantage to the taxi owners when the taxis are due for retirement. It is because there are rules in China that taxis have to retire from service after a certain period (around 5-8 years) or after a certain mileage (approx. 5-600,000 km), the actual requirement varies from city to city. After retirement, instead of being scrapped, these retired taxis are sold to the second hand market for onward sales to 2nd / 3rd tier cities. Unfortunately,, there is no buyer in the second hand market for dedicated LPGV.

(2) AUTOGAS PRICE CONTROL MECHANISMS WERE GOOD FOR CAR USERS BUT BAD FOR AUTOGAS FUELING STATION OPERATORS

Table 4 shows the detailed price control mechanisms in Hong Kong / Shanghai and Guangzhou.

In Hong Kong, only the 12 dedicated Autogas fueling stations are subject to price control because the land for these dedicated fueling stations was provided at nil land premiums and tendered out under Design, Build and Operate (DBO) contract terms for a period of 21 years. The bidders competed primarily for the lowest operating price, i.e. factor B. The operators in Hong Kong do not have to bear any risks in the international price movement of LPG as that is reflected in factor A, adjusted on a monthly basis.

In China, the situation is quite different. Prices of gasoline / diesel and fuel duties have always been under the central government's control. There is, however, no nationwide price control for LPG due to LPG has been historically viewed as a refinery product.

19 Number of Autogas Vs gasoline fueling stations is about 100s (hay period) Vs 700s in Shanghai and 30s Vs 500s in Guangzhou.

20 Other than having more efficient design, OEM vehicles can automatically eliminate the problems of a) conversion from already half run-down gasoline engines; b) incompatibility between LPG conversion kit and original engine; and c) poor conversion skills by sub-standard auto-repair shops.

21 from http://www.96822.com/dz-news/dz-yuekan/2005/2005-10/2005-10-08.htm (accessed Jan 01, 2010)

The local governments realized it was important to provide a profitable environment for Autogas users if they were to promote LPGV in a big scale, however, the central governments polices left them with very little room to enhance the price advantage of Autogas. As a result, both Shanghai and Guangzhou city governments introduced a local price control mechanism for Autogas, which effectively guaranteed an approx. 30% discount of Autogas over gasoline on a per liter basis. While such pricing mechanisms might serve to protect the car users, they put the Autogas fueling stations operators at risks. It is because the Autogas operators could not control their LPG import cost (dictated by the international market), nor their selling price (dictated by domestic gasoline prices). Although price movement of LPG and gasoline usually follows a similar pattern, it fell out of sync in China in the mid 2000s due to government interventions.

During the mid 2000s, crude oil price was shooting up when inflation in China was also rising at a very uncomfortable level. In order to control inflation, the central government put extra pressure to suppress price increase of gasoline and diesel. From Figure 5, it can be seen that when import cost of LPG increased by more than 100% (price of Jan 2005 =1), domestic gasoline price in China increased by around 40-50% only.

Table 4 Autogas Price Control Mechanism for Hong Kong, Shanghai and Guangzhou

Hong Kong	*Shanghai*	*Guangzhou*
Applicable to dedicated Autogas fueling stations only for the full 21-year contract period.	Autogas retailing price was put under Shanghai government's control from Nov 2002	Autogas retailing price was put under Guangzhou government's control from 2004 (a revised formula was used from Jan 2009[22])
$\text{Autogas}_{\text{ceiling retailing price}}$ P = A + B. Where A = LPG international prices adjusted monthly B = operating prices adjusted yearly according to the year-on-year rate of change of the Composite Consumer Price Index for the previous year.	$\text{Autogas}_{\text{retailing price}}$ $=\text{Autogas}_{\text{mid price}} \times (1 \pm A\%)$ $\text{Autogas}_{\text{mid price}}$ = G x K Where G= retailing price of 90# gasoline[23] in Shanghai K= a discount factor between 0.66 – 0.70 to be determined and announced by the government A = adjustment allowance, to be determined and announced by the government (usually in the order of 5-8%) Government would announce $\text{Autogas}_{\text{mid price}}$ and value of A from time to time	$\text{Autogas}_{\text{retailing price}}$ $= \text{Autogas}_{\text{mid price}} \times (1 \pm 8\%)$ $\text{Autogas}_{\text{mid price}}$ = 0.7 x 90# gasoline retailing price in Guangzhou (as announced by Guangzhou Price Bureau)

Consequently, for areas without local government price control on Autogas, car users were finding Autogas losing its competitiveness against gasoline. For Shanghai and Guangzhou where there was price control on Autogas, fueling station operators

22 From 1st Feb 2009, price of auto-LPG is no longer linked to domestic retailing price of gasoline but import cost of LPG.

23 90#, 93# and 97# refers to the octane number of the gasoline blend in China

were forced to run at a loss. As non-compliance with the price control regulations was out of question, many Autogas fueling stations in Shanghai chose to close down or suspend operations to cut losses. In June 2008 when price of crude oil was close to its historical peak, out of 107 fueling stations completed back in 2005, 69 were left, of which 26 suspended operations, only 43 were still in business[24].

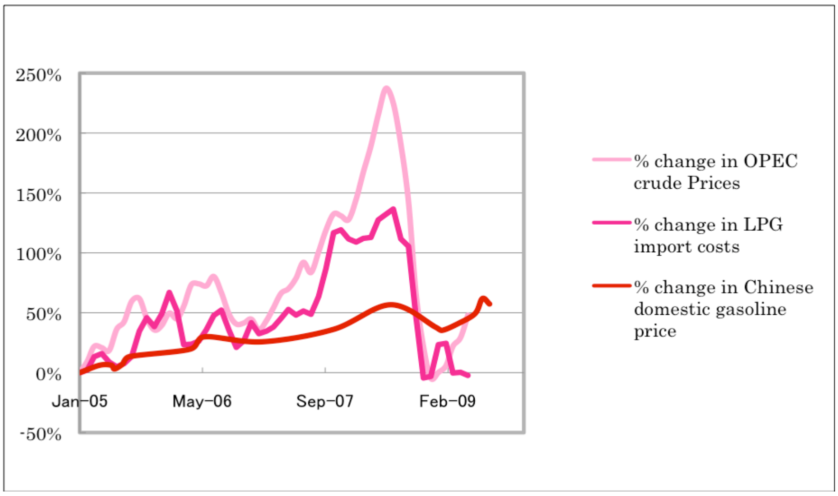


Figure 5 Percentage increase of a) domestic gasoline price in China, b) OPEC crude and c) LPG import costs (price of Jan 2005 =1)

Source:

a) domestic gasoline price: data extracted from http://finance.jrj.com.cn/focus/8thcpyj/index.shtml

b) LPG import costs: Argus FEI index is used as proxy for China LPG import costs, data from Poten and Partners

c) OPEC crude: data from http://tonto.eia.doe.gov/dnav/pet/hist/i060000004m.htm

Some tightness in Autoags supply was observed in Guangzhou but large-scale suspension of operation by Autogas operators was avoided. It was mainly because a) Guangzhou government compensated 80% of the trading losses suffered by fueling stations; and b) close to 90% of the fueling stations in Guangzhou were controlled by two big companies who have had close relationship with the local government.

(3) IMMATURE TECHNOLOGY & POOR QUALITY CONTROL LED TO HIGH MAINTENANCE COSTS

"Technology break-through producing a cost break-through" is one of the key factors that can help to break free of gasoline car technology, according to Cowan & Hulten (1996). LPGV should receive a high score on this regard, as LPGV is a proven technology in many countries like Japan/ Korea and Western Europe. According to WLPGA (2005), maintenance costs of LPGV are lower because "Autogas has a higher octane rating than gasoline, so converted gasoline-powered spark-ignition engines tend to run more smoothly. This reduces engine wear and maintenance requirements, including less frequent spark plug and oil changes. Autogas exhibits less soot formation than both gasoline and diesel, reducing abrasion and chemical degradation of the engine oil. In addition, autogas does not dilute the lubricating film on the cylinder wall, which is a particular problem with gasoline engines in cold

24 from http://www.sh414.com/Html/homeshanghai/2008066760.html, (accessed Jan 02, 2002)

starts."

LPGV, however, was a new technology in China back in the late 1990s / early 2000s. Maintenance costs of LPGV were found to be much higher than gasoline vehicles due to immature technology and poor quality control.

Poor engine adaptability to Autogas composition. Adaptability[25] is a function of a) quality of the original gasoline engine; b) quality of the LPG conversion kit; and c) conversion skills of car mechanics. All three areas needed improvement (Jiang, 2009).

Poor compatibility between LPG conversion kit and gasoline engine. When the taxi market was moving from a couple of models dominating the whole taxi market to multi models co-existing, models for LPG conversion kits also proliferated. Compatibility thus became an issue.

Sub-standard Autogas being supplied at Autogas fueling stations. LPG from most Chinese refineries cannot meet China's standards of specifications for Autogas (coded GB19159-2003) (Cao, 2009). Therefore, except for a small portion of refinery LPG which has gone through special treatment, Autogas requirement was basically met by imported LPG[26]. However, due to loose control, sub-standard LPG was recurrently being supplied at Autogas fueling stations, rendering LPGV prone to mechanical troubles.

In Shanghai, the problem of high maintenance costs became apparent after July 2001. With effective from July 2001, registration of new carburetor engine vehicles was banned and all new gasoline vehicles must be equipped with electronic fuel injection (EFI) engines and catalytic converters. As 2nd generation conversion kits were needed for EFI engines, LPG conversion costs jumped to about CNY6, 500 accordingly. The higher conversion costs compelled car users to the cheaper auto-repair shops, which often were not using the most appropriate equipment or not having the proper skills in converting EFI engines. Poor conversion quality and poor compatibility between conversion kit and engine necessitated repeated re-tuning of the engines, thus driving up the maintenance costs. It was reported that the frequency of troubles was so high that the original carmaker refused to provide after-sale service for, and insurance companies refused to insure, converted vehicles. Also, some taxi companies were said to have prohibited their drivers to use Autogas because while fuel savings went to the driver, maintenance costs were borne by the company.

(4) EXISTENCE OF A LOOPHOLE IN THE LPGV REGULATION IN CHINA (A SIDE-EFFECT FROM BI-FUEL SYSTEM)

The regulations in Shanghai and Guangzhou were not mandating taxis to run on Autogas but the ability to run on Autogas. While there are some dedicated LPG taxis in Guangzhou nowadays, bi-fuel taxis have been the norm. Being able to run on either gasoline or Autogas has been an advantage for LPGV, contributing to LPGV's

25 A properly installed electronically controlled LPG system should have a self-learning property, capable of adjusting the control parameters to account for variations in propane / butane composition, supplied by LPG marketing companies during the year, thus supposedly not necessary to adjust the engine during its life time (Karamangil, 2006).

26 The fact that Autogas needs to be imported should not be blamed for slow LPGV development in China because among Korea/ Turkey/ Poland and Japan, the world's top 4 countries in terms of Autogas consumption in 2007, none of them are blessed with rich domestic LPG supplies.

wide acceptance worldwide. The reason that bi-fuel system became a problem in China was because the price difference in using Autogas and gasoline was so small that many factors could tip the balance. Problems brought by the bi-fuel system are summarized below.

Bi-fuel vehicles are less efficient, thus further reducing the price advantage of Autogas. First, although bi-fuel engines can run on gasoline or Autogas; the engines are not best tuned for burning Autogas thus leading to a slight loss in efficiency. Second, bi-fuel vehicles are running at a lower than optimal compression ratio. LPG has a higher octane rating, which prevents the occurrence of detonation at high engine compression ratio. Hence, engines operating on LPG can run safely at a higher compression ratio than the equivalent engine operating on gasoline. However, the compression ratio in a bi-fuel vehicle is usually fixed by design (Karamangil, 2006).

Bi-fuel vehicles led to a bias in government's policies towards car users. The fact that bi-fuel taxis can run on gasoline if and when Autogas is not available led the government to maximize their effort in mandating car users to switch to LPGV, but conveniently forgetting the importance to provide a profitable environment for the fuel infrastructure providers to establish an efficient Autogas fueling station network. Insufficient fueling stations raised running costs of LPGV, further eroding the advantage of using Autogas.

Bi-fuel vehicle gives the government a false sense of comfort. The mere number of how many taxis had been converted to LPGV gave the authorities a false signal that the LPGV Program was successful. The reality that many of the LPGV in Shanghai were actually not running on Autogas was overlooked.

Bi-fuel system provided an easy way to evade, instead of solving, the technical problems. When many technical problems were found with LPGV during the initial development phrase, if the car users were not able to fall back on gasoline that easily, all parties involved would have to find ways to solve the problems; which might include using better quality conversion kit, providing better training for the car mechanics, appointing only reputable auto shops to carry out the installation jobs; and imposing a tighter control on quality of Autogas being supplied.

Bi-fuel vehicles led to unpredictable sales of Autogas, further increasing the difficulties in running Autogas fueling stations. In countries where there is a favorable price gap between Autogas and gasoline, LPGV users would automatically maximize their use of Autogas as long as they are within the coverage of Autogas supply network. Autogas sales and number of LPGV are therefore closely related. The same logic cannot be applied in China.

The bi-fuel system was more of a problem in Shanghai than in Guangzhou. It is partly because the LPGV technology in China has improved over the years. A more important reason, however, is that Guangzhou has learned the lessons from a) their own failure in late 1990s; b) the failure in Shanghai; and c) the smooth development of LPGV in Hong Kong. When Guangzhou launched their second LPGV program in 2003, more attention has been paid to establishing and ensuring quality standards with respect to LPGV conversion / maintenance and Autogas being supplied at Autogas stations. New dedicated LPG engines, not bi-fuel system converted from half run-down engines, were to be adopted by LPG buses. Although bi-fuel system is still the norm for taxis, the number of OEM dedicated LPG taxis is slowly increasing.

(5)LOCAL POLICIES IN GUANGZHOU FAILED TO EVOLVE WITH TIME

Heavy-duty diesel vehicles are not the best targets to run on Autogas. Not only are the conversion costs / OEM premium much more expensive; the apparent efficiency of Autogas is lower[27], see Table 5 for a detailed comparison between diesel buses and gasoline taxis. This explains why heavy-duty LPGV are not that common worldwide, usually they are seen only in places with very strict environmental regulations (e.g. the use of diesel buses is banned) or where Autogas has a huge price advantage over diesel.

Table 5 Table showing min. discount required for Autogas and breakeven period for LPGV Taxis and LPGV Buses

Type of vehicle	*Type of fuel used*	*Fuel Consumption (liter/ 100km)*	*LPG efficiency (by vol)*	*Conversion / OEM extra costs (CNY)*
Taxi	Gasoline LPG	13.6 15	91%	8,000 – 11,000
Bus	Diesel LPG	40 65	63%	35,000 – 50,000

Source of fuel consumption: Zhang (2009)

Nevertheless, Guangzhou government should not be criticized for their decision to convert diesel buses to LPGV simply because it was not cost-neutral. After all, many regulations, and especially environmental regulations, will incur a cost to the regulated parties. The decision can be justified provided a) the total social benefits are bigger than the total costs; and b) there are no better options available. Back in early 2000s, Guangzhou was plagued with a very serious problem of heavy black smoke emissions from diesel buses. In order to solve this problem, having diesel buses switched to a cleaner fuel like LPG could be the most feasible option at the time. CNG buses were not an option then due to non-availability of natural gas supply. It was not feasible to raise the emission standards quickly as well due to the limitations by a) prevailing domestic technology for diesel engine manufacturing; and b) prevailing quality of domestic diesel fuel.

Problem with the public policies in Guangzhou, however, was during late 2000s, when other low-emission and cheaper options started to appear (e.g. higher-standard diesel engines and diesel fuels, diesel hybrid buses), Guangzhou government were still insisting LPGV to be the only option for buses in Guangzhou.

5 Comparison of historic factors between Hong Kong and China

Although the LPGV program seems to have run smoothly in Hong Kong but not quite in China, it is not fair to give all the praises nor put all the blame to the respective governments. *History does matter.* Other than the difference in fuel duties and pricing mechanism of Autogas and conventions fuels, there are a number of historic factors contributing to the different approaches taken by the governments in Hong Kong and China.

27 Autogas efficiency is lower on a volume to volume basis because Autogas has a lower density than gasoline and diesel. The efficiency deficiency is more obvious with diesel vehicles because intrinsically diesel engine is more efficient than gasoline engine.

An "Isolated" Vs "Connected" City. Hong Kong is small (total area 1095 sq. km) and isolated. There is no worry of LPGV running out of the Autogas coverage area in Hong Kong. The situation is quite different in China. Although taxis are mostly running within the cities, long trips to the suburbs or to other cities are not uncommon. Until a nationwide Autogas supply network is established, bi-fuel system would continue to have an appeal to some taxi owners in China.

"Import" Vs "Domestic" Technology. Car-manufacturing industry is non-existent in Hong Kong, therefore all of the LPG taxis are imported. As for China, developing domestic technology is important to the growing car-manufacturing industry.

"Diesel" Vs "Gasoline" Taxis. Historically, taxis in Hong Kong were running on diesel. Due to technical reasons, conversion for diesel engine is more costly. As a result, Hong Kong did not take the conversion route, but scrapping all old diesel taxis and have them replaced by brand new dedicated LPG taxis.

Since the LPG taxis in Hong Kong can only run on Autogas, the government are more alert of the fact that establishing an efficient Autogas supply network is vital. Moreover, as all LPG taxis are brand new, imported from Japan using proven technologies, their performance of course is more predictable than LPGV converted from half run-down gasoline engines with jobs done by sub-standard car mechanics.

The above explains why the LPGV program in Hong Kong has been much smoother than that in China.

6 Conclusion

The biggest problem in the LPGV development in China during late 1990s to late 2000s was a lack of policy coherence between the central and local governments.

In order to promote Autogas, many countries waive the fuel duties of Autogas either in full or in part. The central government in China, however, by applying ultra low fuel duties on gasoline and diesel, left the local government with very little room to improve the price advantage of Autogas, which became the root of many problems concerning LPGV development in China.

When price advantage was small, voluntary switching to LPGV was unlikely. This explains why diffusion of LPGV in China as a whole was slow. The central government, by not internalizing the benefits of Autogas, failed to correct the problem of consumer externality thus suffocating the development of LPGV.

Nevertheless, some encouraging developments were seen in places with very strong policies towards Autogas. By means of regulations, Shanghai and Guangzhou have had all or nearly all taxis switched to LPGV. Unfortunately, there was a loophole in the regulation as the regulation were not mandating taxis to run on Autogas but only having the ability to run on Autogas. During early 2000s, many of the bi-fuel LPGV in Shanghai were mainly running on gasoline but not Autogas. *Having the LPG system installed but not putting it in use is a waste of resources.*

The way to plug the regulation loophole, however, is not to ban bi-fuel LPGV as the real culprit is not the bi-fuel system but *the price advantage of Autogas being too* *small to cover the high running costs of LPGV*. Efforts, therefore, should have targeted to increase the price advantage of Autogas (via tax & subsidies) and reduce the running costs of LPGV (by monitoring the change in Autogas consumption as well as the change in the number of LPGV; coordinating with the parties involved to solve the technical and poor quality control issues; and encouraging establishment of more Autogas fueling stations).

During the mid 2000s, when price of crude oil and domestic inflation were shooting up, the central government put extra pressure to suppress price increase of gasoline / diesel to put inflation under control. This tipped the balance of Autogas and gasoline, delivering a serious blow to the LPGV development in both Guangzhou and Shanghai. Ironically, in order to suppress price increase of gasoline / diesel, the central government had to make huge cash compensation to Sinopec[28] and Petrochina[29] (the two biggest refiners in China) because these refiners had to import expensive crude at market price and sell them in the domestic markets at prices dictated by the central government. If there were better policy coherence between the central and local governments, the central government should have extended the cash subsidies to local governments like Shanghai and Guangzhou, encouraging them to further step up the use of Autogas. This would have achieved two goals simultaneously: 1) reduce the national energy bill by replacing the more expensive crude oil with the cheaper and cleaner LPG[30]; and 2) provide a super opportunity for LPGV to prosper in China. Unfortunately, such subsides were not made.

Guangzhou has made a number of improvements in drawing up their policies when launching the 2nd LPGV program in 2003, especially with more attention paid to establishing standards and maintaining quality. Although converting diesel buses to LPG buses was not a cheap option, under the prevailing constraints, switching to LPG-buses could be the most feasible option at the time to improve the air quality of Guangzhou city. The problem, however, is when other low-emission and possibly cheaper options started to appear in late 2000s, Guangzhou government still insisted LPGV to be the only option for buses in Guangzhou. It is possible that this is a political decision trying to protect the interest of the Autogas fueling station operators.

Lastly, history does matter. The fact that taxis in Hong Kong smoothly broke free of the gasoline technology is to a great extent due to the favorable historical factors.

28 Sinopec received CNY 12.3 billion compensation in 2008, CNY 5 billion in 2006, CNY 10 billion in 2005 (http://www.18vr.com/2008/3/20/62639.html, http://news.qq.com/a/20080227/000505.htm (accessed Dec 29, 2008)

29 Petrochina received CNY15.7 billion compensation in 2008, http://www.caijing.com.cn/2009-09-18/110254363.html (accessed Dec 29, 2009)

30 when crude oil prices increased by more than 200%, increase for LPG was only about 120-130%, see Figure 5

REFERENCES

Cao, B., 2009. “China Autogas Specifications” (in Chinese), paper presented at the China Autogas Vehicle Forum 2009, Guangzhou, 17-19 June 2009

Chen, J.W., 2006. “Promotion and Exploitation of Autogas, New Contributions of LPG in City Environment Protection”, paper presented at China LPG Conference 2006, Chengdu, Feb 28-Mar 1, 2006

China Automotive Industry Yearbook, 1999 – 2008 (in Chinese), Mechanical Engineering Publishing Company, Beijing.

China Statistical Yearbook 2008, Zhongguo tong ji chu ban she, Beijing

Cowan, R., Hulten, S., 1996. “Escaping Lock-in: the case of the electric vehicle”, Technology Forecasting and Social Change) 1996, vol 53(1), 61-80

E1 Corp., 2009. “LPG in Korea, Trend and Outlook”, paper presented at International LPG Seminar 2009, Tokyo, Feb 26-27, 2009

GDOGA, 2007. “China LPG Report 2006” (in Chinese), Guangdong Oil & Gas Association, Guangzhou

Gong, Y.L. 2009. “LPG Vehicle Development in Guangzhou” (in Chinese), paper presented at the China Autogas Vehicle Forum 2009, Guangzhou, 17-19 June 2009

Grand, J., 1991. “The Theory of Government Failure”, Journal of Political Science, Vol. 21 No. 4 (Oct;, 1991), pp 423-442

Hong Kong Government, (1999-2008), “Annual Transport Digest”, Hong Kong Government, Hong Kong, 1999-2008

Japan LP Gas Association. http://www.j-lpgas.gr.jp/feature/environment.html

Jiang, L. 2009. “Experience from Choosing LPG Vehicle Conversion Equipment in Hangzhou” (in Chinese), (paper presented at the China Autogas Vehicle Forum 2009, Guangzhou, 17-19 June 2009)

Karamangil, M.I., 2006. “Development of the LPG and LPG-powered vehicle sector in Turkey: A statistical case study of the sector for Bursa”, Energy Policy 35 (2007), 640-649

Köhler, J. et al, 2008. “Can car makers save the planet?” in Foxon, T.J. et al (eds) “Innovation for a Low Carbon Economy – Economic, Institutional and Management Approaches”, Cheltenham, UK and Northampton, MA, USA: Edward Elgar

Pang, J.G. & Sun, C.W., 2001. "Brief Discussion on Shanghai Autogas Market" (in Chinese), International Petroleum Economics, 2001, vol 8, pp16-17

Shi, J.M. 2003. "Shanghai LPG Development and Forecast" (in Chinese), Paper presented at 5th China Gas Seminar, Heilongjiang, Aug 26-29, 2003

State Steering Group on Clean Car Act Project, 2002. “Review and Prospect of Gas Vehicles in China” (in Chinese), paper presented at China LPG Conference 2002, Haikou, Mar 14-15, 2002

Unruh, G., 2000. “Understanding carbon lock-in”, Energy Policy 28 (2000) 817-830

Winston, C., 2006. “Government Failure Versus Market Failure: Microeconomics Policy Research and Government Performance”, Brookings Institution Press

WLPGA, 2005. LPG Incentive Policies. Paris: World LP Gas Association and Menecon Limited

WLPGA, 2009. “Autogas and LP Gas Distribution in a Low Carbon World”, paper presented at International LP Gas Seminar, 2009, Tokyo, 26-27 Feb, 2009

World LP Gas Association. http://www.worldlpgas.com/

Yang, H.H., Chien, S.M., Cheng, M.T. and Peng, C.Y., 2007. “Comparative Study of Regulated and Unregulated Air Pollutant Emissions before and after Conversion of Automobiles from Gasoline Power to Liquefied Petroleum Gas/ Gasoline Dual-Fuel Retrofits”, Environmental Science & Technology., 2007, 41 (24) 8471-8476

Zhang, Q.D. 2009. “Reform and Outlook of Guangzhou Autogas Price Mechanism” (in Chinese), paper presented at the China Autogas Vehicle Forum 2009, Guangzhou, 17-19 June 2009

Change in Shanghai's Motor Vehicle Fleet Size, with the Focus on the License Plate Auction System

Zhe FU[1]

1. Introduction

On January 11, 2010 the China Automobile Industry Association announced that in 2009 China had produced 13,791,000, with sales of 13,644,800, thereby propelling China past the United States to become the world's top country in terms of motor vehicle manufacturing and sales. This indicates that china's automobile industry has developed to considerable size.

One factor behind automobile industry development is motorization, which is of course a social phenomenon in which the possession of motor vehicles (especially passenger cars) by households increases, as does vehicle use in everyday life.

Motorization is perceived as a synonym for an affluent life, but as one can see from the examples of developed countries, it has brought about grave environmental problems (such as air pollution, noise, and declining quality of life due to traffic congestion) in urban areas. Improving one's understanding of motorization is important for considering how to deal with environmental problems.

Using Shanghai[2] as an example, this paper discusses the trend in motor vehicle ownership, which is a major cause of motorization, by examining its historical changed since reform and opening. The reasons for choosing Shanghai are that the city has a policy that is unusual (illegal from the government's point of view) for China on personal vehicle ownership, and that the city government maintains a license plate auction system. This paper is primarily an analysis of how this system influences the trend in vehicle ownership. Following is an overview of the Shanghai vehicle ownership trend over the three decades since reform and opening.

2. Overview of Shanghai Vehicle Ownership Trend Over the Three Decades Since Reform and Opening

Figure 1 plots Shanghai's total vehicle fleet size from reform and opening (1978) to the present (2008). As the graph shows, vehicle ownership has tended to increase through the 1980s, 1990s, and 2000s.

Tables 1 through 3 provide the breakdown of ownership in the 1980s, 1990s, and 2000s. To maintain data consistency, however, data are not strictly arranged according to decade.

From 1978, when reform and opening started, to 1988, the number of vehicles owned increased by a factor of about 2.4 (Table 1). The breakdown shows that the number of passenger vehicles[3] (excluding large vehicles) increased 5.7 times, with the proportion of the total rising from 11.13% in 1978 to 26.82% in 1988. Although the proportion of trucks decreased from 65.89% in 1978 to 57.97% in 1988, the percentage is still high.

Trucks were indeed the leading product of China's automobile industry before reform and opening. According to data compiled by Liu (2005), in 1976 the major 11 manufacturers produced 100,139 units, of which only 2,600 units, or 2.6%, were passenger cars.[4] After

---

[1] Graduate School of Economics, Hitotsubashi University. Naka 2-1, Kunitachi-shi, Tokyo, 186-8601.

[2] This paper distinguishes between "Shanghai," which means the general geographical area, and "Shanghai City," which refers to an administrative and policy entity.

[3] In China buses and passenger cars are put in a "passenger vehicle" category.

[4] China's total 1976 automobile production was 135,200 units, with production by the major 11 producers accounting for 74.1%. See Liu (2005), pp. 233–235.

reform and opening the increase in passenger cars started with imported vehicles. *China Automotive Industry Yearbook* indicates that in 1980 China imported a total of 19,570 vehicles, and 105,775 vehicles in 1985.[5]

Full-fledged passenger car production in China started with joint ventures with foreign companies.[6] For example, in October 1984 China National Automotive Industry International Corp, Shanghai Automotive Industry Corporation, Bank of China, and the Shanghai Trust and Consulting Company together established a joint venture with Germany's Volkswagen called "Shanghai Volkswagen Automotive Company Ltd.," which produced 3,356 Santana vehicles in 1985, 8,031 units in 1986, and 10,470 units in 1987.[7]

According to *China Automotive Industry Yearbook*, the percentage of passenger vehicles in total automobile production in the first half of the 1980s stayed under 3%, and although it increased in the second half, it never exceeded 6%.[8]

Amid these supply-side limitations, during the 11 years after reform and opening (1978 to 1988) automobile ownership in Shanghai increased 2.4 times in terms of total ownership, and 5.7 times in terms of passenger vehicles (excluding large vehicles). Fleet expansion rapidly increased vehicular traffic, and in the mid-1980s Shanghai City started having serious traffic congestion.

With the coming of the 1990s, the Chinese government put effort into developing automobile production and widening automobile use. In 1992 the 14th National Congress of the Communist Party of China decided that the automobile industry would be given a place as a "pillar industry." In the way of concrete policy, in 1994 the government promulgated the "Industrial Policy for the Automobile Industry," which comprised 13 chapters and 61 articles. This formed the basis for legislation for actively bringing in foreign capital and improving the technological capabilities of domestic manufacturers. Policy on consumption and prices was also set so that automobile purchases by individuals would be encouraged, and so that automobile companies would be able to decide their own prices in response to market demand.[9]

In the 1990s the Chinese government endeavored to raise the automobile industry's supply capacity and to widen motor vehicle use, and during the 12 years from 1989 to 2000, which subsumed that decade, Shanghai's total motor vehicle fleet grew 3.6 times (Table 2). During the approximately 20 years since reform and opening, the fleet grew by a factor of 8.1. Passenger vehicles increased 6.7 times in 12 years, and 28 times during the approximately 20 years since reform and opening. During these 12 years ownership by individuals increased 12.7 times for motor vehicles as a whole, and 24.7 times for passenger vehicles. In particular, total personal motor vehicle ownership in 1999 was 2.7 times greater than the previous year, and in 2000 it doubled yet again. In these two years the trend in automobile ownership was characteristically different from that of 1998 and previous years.

Then arrived the 2000s, and China joined the WTO (late 2001), which brought pressure to bear on China to change its automobile industry policy. WTO membership made it impossible to continue implementing protective policy prescribed by the "Industrial Policy for the

---

5 According to Harwit (1995), most vehicles were imported from Japan. Taxi companies in particular were highly desirous of the Toyota Crown and the Nissan Bluebird. See Harwit (1995), pp. 29–30.
6 On the trends in the establishment of joint ventures with foreign-capital firms in the automobile industry after reform and opening, see Liu (2005) and Harwit (1995).
7 See Harwit (1995), p. 99.
8 See also Harwit (1995), p. 32.
9 For details, see Liu (2005), pp. 295–296.

Automobile Industry," such as regulating the percentage of domestic production, restricting entry by foreign manufacturers, and limiting imports.[10] This made the automobile industry more competitive.

As great changes occur in the circumstances surrounding the automobile industry, during the eight years from 2001 to 2008 Shanghai's total motor vehicle fleet increased 2.4 times (Table 3). It grew by a factor of 25.2 during the approximately 30 years since reform and opening. During the eight-year period passenger vehicles increased about three times, and in the 30 years since reform and opening the number became a whopping 122 times greater. During the eight-year period, personal ownership of motor vehicles overall increased 8.3 times, while that of passenger vehicles increased 8.6 times. In particular, personal ownership of passenger cars became 8.9 times higher, for the highest rate of increase in this period.

Examining only the total motor vehicle fleet size of Shanghai for the approximately 30 years since reform and opening in 10-year segments reveals a steadily greater increase of 2.3 times in the first decade (1978–1987), 3.1 times in the second decade (1988–1997), and 3.4 times in the final period (the 11 years from 1998 to 2008).

3. Shanghai City's Motor Vehicle Ownership Regulation Policy: Overview of the License Plate Auction System

As we saw in the previous section, Shanghai motor vehicle ownership has ballooned over the last 30 years. But the 2.3-fold ownership increase in the decade after reform and opening engendered serious traffic congestion in Shanghai, thereby strongly motivating city authorities to hold down total traffic volume. Following is an overview of the motor vehicle ownership regulation policy adopted by the Shanghai City government starting in the second half of the 1980s.

In 1987 the city government collaborated with involved departments including police and public finance (Social Group Purchasing Power Regulation Office, below, "Regulation Office") in working out measures to hold down vehicle fleet size. Under the policy, the Regulation Office would review each request to acquire an automobile (passenger car or large passenger vehicle) or two-wheel vehicle, and then permit the issuance of a license plate. In other words, the police department agency's vehicle control office would issue a license plate based on a purchase permit issued by the Regulation Office. But in the 1990s as demand for privately owned passenger cars increased, this administrative review and permit system was no longer able to cope. Facing this situation, the Shanghai City authorities conducted a study on Singapore, which has a license plate auction system, in a bid to find a stronger policy for fleet size control in order to relieve traffic congestion.[11] A major motivation behind Singapore's launching of its license plate auction system in 1990 was that, as the country became more affluent, the automobile acquisition tax and other measures were no longer able to effectively restrain the growth of automobile ownership.[12]

On July 18, 1992 Shanghai City held its first open license plate selection (in which people choose the best, or lucky, number) auction for passenger cars owned by individuals.[13] On the auction's first day, the plate with the best lucky number went for the high price of 305,000 yuan. On that day 14 license plates were auctioned off for a total of 2,244,000 yuan, or an average of 187,000 yuan each. In those days the price of a Santana vehicle was 200,000 yuan, but the price

[10] On China's automobile industry policy since the 2000s, see Marukawa and Takayama, eds. (2005), pp. 69–71.
[11] See Wang (2010), p. 149.
[12] See Koh (2004).
[13] See Lü (2009), pp. 11–13. See also Tao (2008), pp. 58–60.

of a license plate was between 100,000 and 300,000 yuan.

In June 1994 the Shanghai City Planning Commission (which is now the Shanghai City Development and Reform Commission) and the Shanghai City Police Department worked together in deciding on the "Law on Auctioning of License Plates for Privately Owned Automobiles and Two-Wheel Vehicles in Shanghai City" in order to control the size of Shanghai's vehicle fleet and mitigate traffic congestion.[14] To obtain license plates for passenger cars owned by private-sector companies and individuals, it was now necessary for them to participate in a closed-bidding auction.[15] Further, bidding started at 100,000 yuan. In those days there were still few people who could afford cars, and only a few hundred license plates were auctioned each month. There were separate registration rules for trucks.[16]

In June 1998 Shanghai City lowered the initial bidding price to 20,000 yuan for Santana vehicles, which are made by Shanghai-based Shanghai Volkswagen, while at the same time starting bidding for automobiles made in other places (including imports) at 100,000 yuan. While the number of plates issued for individually owned passenger cars before June 1998 was 4,205, that increased to 11,293 for the period from June 1998 to the end of 1999.[17] The number issued steadily increased after that.

In January 2000 the People's Congress of Shanghai enacted the "Shanghai City Automobile Control Ordinance", canceled the previous policy, and changed the auction system to one with no initial bidding price for domestically made noncommercial vehicles carrying 19 or fewer passengers. This system applied to all domestically manufactured vehicles, while there was a separate license plate auction for imported cars (bidding for imports started at 50,000 yuan).[18] In 2000 Shanghai City issued 14,000 license plates.

In consideration of China's joining the WTO, in March 2003 the license plate auction system was again changed to have no starting bid price for all domestic vehicles and imports

---

[14] This law is for internal use only and not made public, making it impossible to find out the license plate auction system's purpose, which can only be divined from statements by officials of the Shanghai City government. For example, Shanghai City Government Press Secretary Jiao Yang explained it thus at a press conference: "The purpose is to control the rapid increase in the motor vehicle fleet and mitigate traffic congestion on our streets." See Shanghai City Government Press Conference Record (May 25, 2004), and Shanghai City Government Website <http://www.shanghai.gov.cn/shanghai/node2314/node9819/node9820/userobject21ai86189.html> (viewed on June 18, 2010).

[15] Article 13 of the "Shanghai City Traffic Control Ordinance" establishes the auction's implementation rules. The article reads thus: "Shanghai City shall exercise control over the total number of vehicle license plates. The number of license plates issued per year and the method of issuance shall be proposed by the Shanghai City Planning Commission, Shanghai City's police and traffic control departments, and other related departments, and the auction shall be carried out after receipt of applications and approval by the Shanghai City People's Government."

[16] For an overview of the license plate auction system, which was launched in 1994, see also Koyama (2006).

[17] See: State Information Center and National Planning Commission Industrial Development Office, ed. *2001 China Automobile Market Outlook*.

[18] See "Shanghai to Auction Private Car License Plates," *China Youth Daily*, November 20, 2007, posted at *China Police Daily* <http://www.cpd.com.cn/gb/jcwz/2008-01/21/content_899763.htm> (viewed on June 18, 2010).

for 19 or fewer passengers, and to auction all together. That system survives to the present.[19]

Table 4 compares the number of plates issued annually under the license plate auction system since 2002, and the increase in passenger cars owned by individuals and covered by the auction. The number of plates issued tended to increase, from 30,000 to 80,000. This restricts the size of Shanghai's fleet, while at the same time satisfying consumer needs.[20]

As one can see from Table 4, the number of license plates issued by auctions accounts for 80 to 90% of the increase in passenger cars. One reason that the figure is not 100% is that people who already own cars do not have to get new plates when replacing their vehicles. Another reason is that vehicles whose purchase and use are limited to the Shanghai City suburban areas do not need to get license plates through the auction system.[21]

The next section will use a comparison with other regions to examine how the license plate auction system has influenced automobile ownership by individuals[22] in Shanghai City.

To wrap up this section, here is a brief summary of revenues and expenditures of the license plate auction system.[23]

Revenues from 1994 to 2006 totaled 9.42 billion yuan. Of this, 3.9 billion yuan were used for construction of the Central Ring Road, 3.6 billion yuan were spent on construction of railways, and 230 million yuan were spent on traffic management facilities.

Revenues for 2007 and 2008 totaled 6.26 billion yuan. Of this, 2.3 billion yuan were spent on railroad construction for the Shanghai Shentong Metro Group Company Limited, and 1.5 billion yuan were spent on railroad construction for the Shanghai Chengtou Corporation. One billion yuan were expended on repayment of principle and interest payments for the Central Ring Road project, and a subsidy of 856 million yuan was provided for special public transportation items.

Although income from the auction system is less than 1% of Shanghai City's revenues, much is spent on the construction of rail transport, an alternative to motor vehicles.[24] On this

---

[19] See "Difficult to Maintain or Abolish Shanghai Car License Plate Auction," *Caijing*, 2008 Second Period, January 21, 2008, posted at Caijing Net <http://magazine.caijing.com.cn/2008-01-19/110065962.html> (viewed on June 18, 2010).

[20] Although the number of plates issued for individually owned passenger cars has been increased, the number issued for publicly owned vehicles is strictly limited. See: Shanghai City Government Press Conference Record (April 20, 2004), posted at Shanghai Government Net <http://www.shanghai.gov.cn/shanghai/node2314/node9819/node9820/userobject21ai86189.html> (viewed on June 18, 2010).

[21] According to State Information Center and National development and reform commission Industrial Development Office, ed. *2001 China Automobile Market Outlook*, in 2005 ownership in the Shanghai City suburbs was 13,000, replacement demand was 32,000 units, and 13,000 license plates were issued for taxis. In 2006 the plate issuance numbers were, respectively, 16,000, 58,000, and 16,000; in 2007 they were 22,000, 50,000, and 12,000; and in 2008 they were 23,000, 36,000, and 7,000. As these figures show, automobile ownership is steadily increasing in the Shanghai City suburbs in conjunction with development of the suburbs, and it supports the development of the Shanghai City automobile market. See *2009 China Automobile Market Outlook*, p. 276.

[22] Owing to limitations in the data, the analysis is for motor vehicles (including trucks) owned by individuals, not passenger cars owned by individuals.

[23] For details, see: Shanghai City Government <http://www.shanghai.gov.cn/shanghai/node2314/node2319/node23197/node23198/userobject21ai348058.html> (viewed on June 18, 2010).

[24] Singapore likewise spends auction proceeds on alternative transportation construction. See

point the Shanghai City government positively evaluates the system: “The license plate auction system has been useful in holding down fleet size, mitigating traffic congestion on city streets, and in guaranteeing the implementation of our strategy to give priority to public transportation.”[25]

4. Influence of Shanghai City’s License Plate Auction System on the Trend in Personal Automobile Ownership

In Section 2 we saw that total personal automobile ownership in 1999 was double that of the previous year. This corresponds to a rapid increase in plate issuance by the license plate auction system, as seen in Section 3. The subsequent trend toward additional passenger car ownership can be largely explained by the number of plates issued under the auction system, as shown in Section 3 and Table 4.

Riley (2002), Liu (2005), and Deng (2007) observe that, in addition to the income factor, the factor of policies specific to local governments (including central government policies) are important to an understanding of automobile ownership trends in China. In particular, Deng (2007) compared the ranking according to income per household member and the number of individually owned automobiles per 100 households in provinces and in directly governed cities, and discovered that although Shanghai ranked first in terms of income, it never attained the highest ranking in terms of automobiles owned, and that there was often no correspondence of ranking in other provinces or in directly governed cities other than Shanghai. Deng (2007) argued that regional differences in personal ownership of automobiles is caused by policy factors in each region, and that regional differences in personal automobile ownership in China cannot be explained by the income factor alone.[26]

The factor of policies specific to local governments observed by Deng (2007) is, in the case of Shanghai City, the license plate auction system. This section discusses the singularity that the system brings to automobile ownership in Shanghai.

To begin with, I shall use 2008 data for provinces and directly governed cities to examine the relationship between per capita GDP and the number of individually owned automobiles per 1,000 people. Figure 2 is a scatter chart that plots these two sets of data. If Beijing and Tianjin are seen as standard, then Shanghai is peculiar. That is, even though per capita GDP is high, automobile ownership is low (38.15 units). That is about the same as the Inner Mongolian Autonomous Region (36.38), whose per capita GDP is less than half that of Shanghai. From Figure 2 one can discern that except for Shanghai, on the whole car ownership increases with as per capita GDP rises.

Next I used data for provinces and directly governed cities from 1999 to 2008, when automobile ownership in Shanghai doubled, to calculate the per capita GDP elasticity of the number of individually owned vehicles per 1,000 people. Figure 3 is a scatter chart that plots

---

Koh (2004).

[25] See: Information Office of the State Council <http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/shanghai/200905/t320893.htm> (viewed on June 18, 2010).

[26] Similarly, the author used data on per capita GDP and the number of individually owned automobiles per 1,000 people for the years 2001, 2005, and 2008 in a ranking comparison of provinces and directly governed cities. Although the comparison found differences with Deng (2007) in the ranking for the number of individually owned automobiles, it did coincide with Deng’s finding that even though Shanghai City consistently ranked first in terms of per capita GDP, it never ranked first in the number of individually owned automobiles, and in many regions the comparison found no correspondence between GDP and automobile ownership.

the average per capita GDP (calculated for an estimation period) for provinces and directly governed cities, and elasticity.

Figure 3 shows that Shanghai has both the largest per capita GDP and the largest elasticity (2.7426). Beijing has the next-biggest per capita GDP, but small elasticity (1.0083), as does Tianjin City (1.0058). When Beijing and Tianjin are used as the standard, it becomes clear that Shanghai is singular.

Compared with other regions, the singularity of Shanghai's trend in personal automobile ownership permits the conjecture that it is due to the license plate auction system. To examine this in greater depth, I shall consider Beijing and see how it is different.

According to *2010 China Automobile Market Outlook*, automobile purchases in 2009 by high-income Beijing residents were within the replacement cycle.[27] If one considers this in conjunction with the small elasticity value for Beijing from 1999 to 2008 as seen in Figure 3, it can be understood as meaning that in 2008 the Beijing households that can afford to buy automobiles had attained or approached the saturation point in terms of automobile ownership. But the reason that Shanghai's elasticity is large compared with that of Beijing seems to be that while on the one hand those household that can afford to buy cards have a great need to have them,[28] that household group still has a low car ownership level and endeavored to purchase them. Table 5 shows the elasticity of Shanghai and Beijing from 1999 to 2008, plus those for 1988 to 1998. As we saw in Section 3, in 1998 and previous years Shanghai City's license plate auction system issued a low number of plates. It is likely for that reason that from 1988 to 1998 Shanghai's elasticity was below 1. By contrast, that of Beijing is large at 1.9746, showing that personal car ownership in 1998 and previous years grew rapidly. Further, in 1999 and thereafter elasticity is small, which corroborates the above statement that Beijing households that can afford cars are nearly at the ownership saturation point. Table 5 shows elasticity of 1994 and previous years, and of subsequent years, for the period from 1988 to 1998. In 1994 the central government promulgated the "Industrial Policy for the Automobile Industry," which encouraged personal car ownership. It was also the year that Shanghai City instituted its license plate auction system. Elasticity values for the two cities have different characteristics. Shanghai's elasticity became smaller after the auction system was instituted. The reason seems to be that the auction system more strongly controlled automobile ownership in Shanghai. Beijing's elasticity became larger after promulgation of the policy, which appears to be due to acceptance of the central government's policy encouraging personal car ownership.

The above discussion makes it clear that Shanghai City's license plate auction system resulted in singularities distinguishing it from other places, especially Beijing City.

Finally, Shanghai City's auction system has brought about one more singularity in Shanghai's automobile ownership trend: Owing to the fluctuating price of license plates, the auction system as introduced uncertainty into the cost of automobile ownership, and influenced consumers' automobile purchase plans.[29] In Shanghai the cost of car ownership is trending upward,[30] and because of that some people have since about 2002 been getting license plates in

---

[27] See: State Information Center and National development and reform commission Industrial Development Office, ed. *2010 China Automobile Market Outlook*, p. 255.

[28] Shanghai's four major jointly media conducted the "2009 Large-Scale Survey on Automobile Demand Among Shanghai Youth," which found that there is high demand for cars among youth, that about 85% of young people have annual income of 100,000 yuan or higher, and that they can afford to have cars. See: <http://www.cnnauto.com/subject/game/151252.shtml> (viewed on June 18, 2010).

[29] See: Koh (2004).

[30] For specific examples, see: Shanghai City Information Center

the nearby provinces of Jiangsu, Zhejiang, and Anhui. The numbers of automobiles with license plates obtained in Shanghai City's suburban cities are 15,531 in 2005, 22,688 in 2006, and 24,993 in 2007.[31]

5. Conclusion

This paper first provided an overview of the automobile ownership trend in Shanghai, and then showed that Shanghai has greatly increased automobile ownership since reform and opening. However, Shanghai City has adopted a license plate auction system, a unique policy not seen in other Chinese cities, which has held down the growth of Shanghai's motor vehicle fleet. Thanks to the system's effectiveness, as of 2008 Shanghai, which has the highest per capita GDP in China, and also the largest elasticity of personal car ownership to per capita GDP, has kept the level of ownership per 1,000 people at a low level.

However, Shanghai City's license plate auction system was implemented as a measure to control fleet size and to avoid and prevent traffic congestion. Although this paper was able to demonstrate that Shanghai City's auction system created a trend in personal car ownership in Shanghai that was singular in comparison with trends in other places, it does not discuss whether the system was effective as a means of avoiding and preventing traffic congestion. Wang (2010) presents as evidence the acquisition of license plates in the Shanghai outskirts, as described at the end of Section 4, to argue that the auction system cannot limit Shanghai automobile ownership, or avoid or prevent traffic congestion. Wang also claims that the Shanghai City government must focus on the connection between automobile ownership and use, and must explore measures for automobile use conditions based on Shanghai City's urban structure. Koh (2004) argues that the license plate auction system should not be evaluated according to whether it has been able to prevent or avoid traffic congestion because fleet size control by means of the auction system influences the magnitude of potential traffic congestion instead of controlling actual traffic congestion. Therefore, he says, the system should be evaluated on the basis of whether the city has achieved the planned fleet size. In any case, apart from the Shanghai City government's evaluation at the end of Section 3, I shall leave the evaluation of the system to another time.

Another consideration is that the central government demands that Shanghai City abolish its license plate auction system on the grounds that it is illegal. While the Shanghai City government intends abolish the system, it has taken a strong position[32] on keeping the system in operation until it completes measures (public transportation systems and construction of urban roads) to prevent and avoid environmental problems caused by rapid motorization. I shall use another occasion to discuss what the Shanghai City government means by measures to prevent and avoid environmental problems.

Finally, as noted at the end of Section 3, revenues from the license plate auction system are used to fund construction of alternative transportation systems. For the actors involved with motor vehicle pollution and traffic congestion to assume the burden of environmental costs associated with measures to avoid and prevent environmental problems is commendable for anticipating the commitment principle of Teranishi (2007).

<http://www.news365.com.cn/wxzt/hcjzspsz/hcspxgxw/t20040316_44185.htm> (viewed on June 18, 2010).

[31] See: State Information Center and National development and reform commission Industrial Development Office, ed., *2007 China Automobile Market Outlook*, p. 240.

[32] See: *Jiefang Online* <http://trs.jfdaily.com/xwcb/page_3/200902/t20090227_552477.html> (viewed on June 18, 2010).

References

[Japanese literatures] (all in Japanese)

Koyama, Shinya (2006), “Management of motor vehicles ownership by license plate auction in Shanghai and Singapore(Shanghai-shi to Singapore niokeru Auction wo kastuyousita jidousya hoyudaisu no kanri) ,” *A Viewpoint to East Asia (Higashi Ajia he no Shiten)*, September, pp.1-14.

Teranishi, Shunichi (2007), “Chief editor interview: How Prof. Teranishi looks at Social costs involved with environment (Hensyucho interview; Kankyo nikakawaru Syakaiteki hiyou wo do kanngaeruka, ” *Quarterly Journal of Public Policy & Management (Kikan seisaku/keiei kenkyu)*, pp.159-174.

Marukawa, Tomoo and Yuichi Takayama eds. (2005), *New Edition Chinese automobile industry under global competitive age* (*Shinso Global kyousoujidai no chugoku jidousya sangyo)*, Soussou-sya.

Liu, Yuanzhang (2005), “Part 3, Development and challenge of Chinese automobile industry (Dai3bu chugoku no jidousya sangyo-hatten to kadai), ” *Automobile industry in Asia and challenge of China* (*Asia no jidousya sangyo to chugoku no chousen)* edited by Shinichi Ichimura, pp.187-397, Soubun-sya.

[English literatures]

Deng, Xin (2007), “Private Car Ownership in China: How Important is the effect of Income?”, <http://www.ecosoc.org.au/files/File/TAS/ACE07/presentations%20(pdf)/Deng.pdf > (viewed on June 18, 2010).

Harwit, Eric (1995), *China's automobile industry*, M.E. Sharpe.

Koh, Winston T.H.(2004), “Congestion Control and Vehicle Ownership Restriction: The Choice of an Optimal Quota Policy,” *SMU Economics & Statistics Working Paper Series,* paper no.03-2004.

Riley, Kevin (2002), “Motor Vehicles in China: The Impact of Demographic and Economic Changes,” *Population and Environment*, vol.23, no.5, pp.479-494.

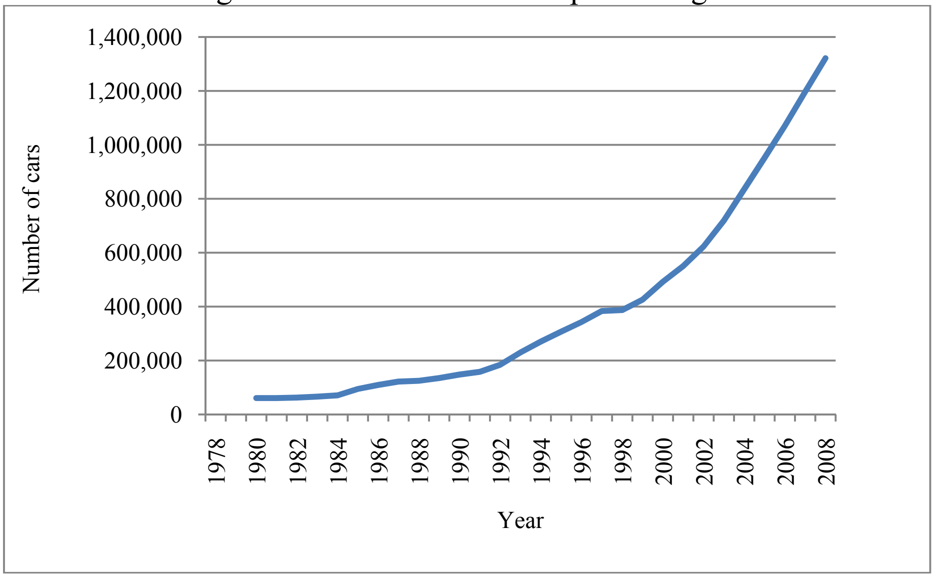
Wang, Rui (2010), “Shaping urban transport policies in China: Will copying foreign policies work?,” *Transport Policy*, vol.17, pp.147-152.

[Chinese literatures] (all in Chinese)

Lü, Di (2009) , “Economic Analysis of Shanghai Vehicle Quota License auction Policy (Shanghai ji dong che pai zhao e du pai mai zheng ce jing ji xue fen xi),” Public Utilities(Cheng shi gong yong shi ye), Vol.23, No.6, pp.11-13.

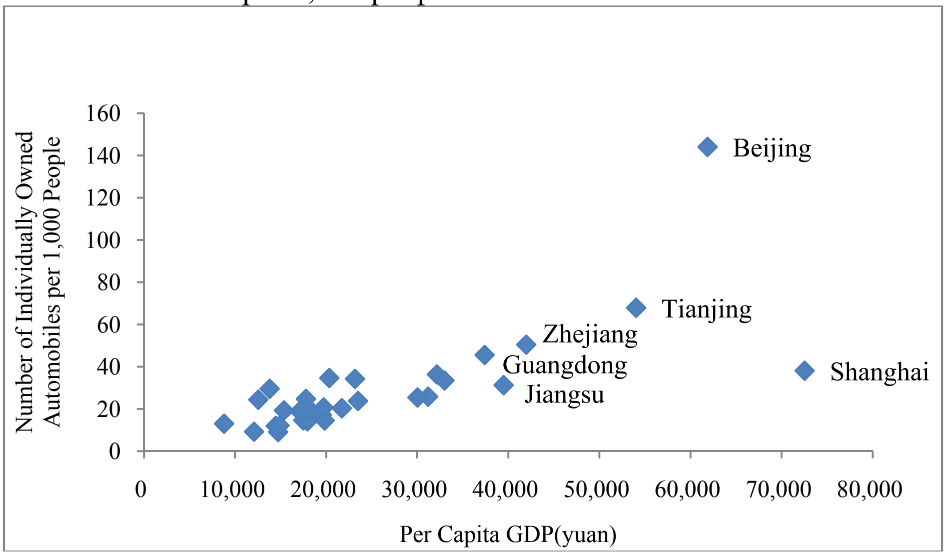
Tao, Lin (2008) , “Legal Research of Shanghai automotive licenses auction policy (Shanghai ji dong che hao pai pai mai zhi du de fa lü yan jiu),” Traffic and Transportation(Jiao tong yu yun shu), No.2, pp.58-60.

Fig.1 Total vehicles ownership in Shanghai



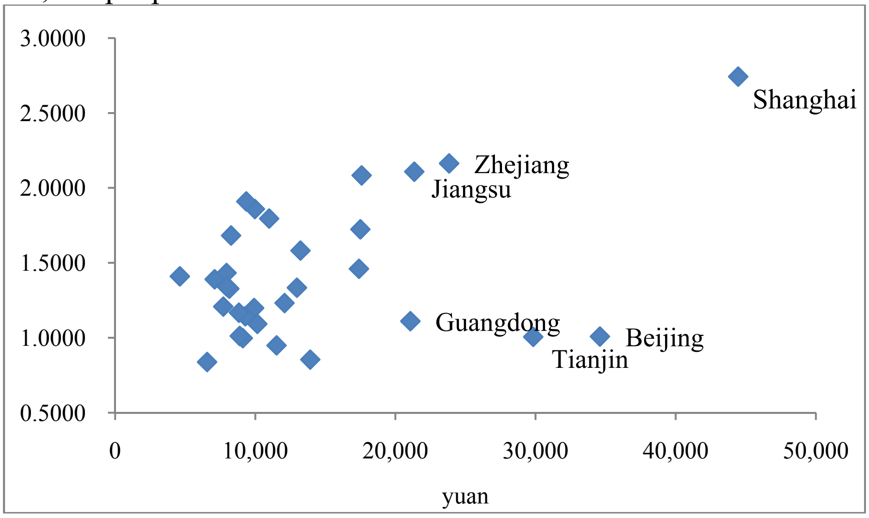
Source: Each year edition of *Shanghai Statistical Yearbook*.

Fig.2 The Relationship between per capita GDP and the number of individually owned automobiles per 1,000 people in 2008



Source: *China Statistical Yearbook* (2009).

Fig.3 The per capita GDP elasticity of the number of individually owned vehicles per 1,000 people



Source: Each year edition of *China Statistical Yearbook*.

Table 1 Automobile (civil vehicle) and motorcycle ownership in Shanghai, 1978-1988

			1978	1980	1981	1982	1983	1984	1985	1986	1987	1988
Automobile			52,456	60,469	60,851	62,543	66,159	70,969	94,423	109,299	121,791	124,666
Detail	Passenger Vehicles		9,079	11,657	11,996	12,179	13,605	15,518	26,041	33,334	39,922	44,282
		Large	3,239	4,315	4,758	5,075	5,613	6,162	7,707	9,110	10,071	10,851
	Freight Trucks		34,562	38,944	39,338	40,824	42,766	45,349	54,607	61,227	66,131	72,275
		Large	20,845	23,660	23,094	23,886	24,570	26,044	30,135	32,691	35,497	40,300
	Other Automobiles		8,815	9,868	9,517	9,540	9,788	10,102	13,775	14,738	15,738	8,109
Motorcycle			8,351	10,540	14,016	15,173	14,984	15,042	14,511	19,499	31,401	32,945

Source: Each year edition of *China Statistical Yearbook* and *Shanghai Statistical Yearbook*.

Table 2 Automobile (civil vehicle) and motorcycle ownership in Shanghai, 1989-2000

		1989		1990		1991		1992	
			Private		Private		Private		Private
Automobile		134,997	3,987	147,692	3,755	158,227	3,814	184,290	5,122
Detail	Passenger Vehicles	48,987	1,922	54,586	1,583	62,180	1,556	79,575	2,781
	Freight Trucks	74,610	2,065	79,192	2,172	83,623	2,258	91,118	2,341
	Other Automobiles	11,400	—	13,914	—	12,424	—	13,597	—
		1993		1994		1995		1996	
			Private		Private		Private		Private
Automobile		230,040	8,145	270,155	6,773	307,050	8,045	342,771	9,198
Detail	Passenger Vehicles	113,785	5,640	141,655	4,026	170,040	5,041	196,603	6,016
	Freight Trucks	100,355	2,503	110,957	2,744	119,440	3,002	126,584	3,179
	Other Automobiles	15,900	2	17,543	3	17,570	2	19,584	3
Motorcycle		68,123	48,867	78,214	54,316	89,112	60,467	98,707	65,116
		1997		1998		1999		2000	
			Private		Private		Private		Private
Automobile		383,372	10,063	386,849	9,153	425,463	24,608	491,929	50,658
Detail	Passenger Vehicles	226,575	6,818	244,270	6,186	276,836	21,449	326,863	47,527
	Freight Trucks	134,645	3,242	123,088	2,965	128,584	3,157	143,788	3,129
	Other Automobiles	22,152	3	19,491	2	20,043	2	21,278	2
Motorcycle		130,236	82,077	183,251	85,023	238,250	195,510	537,691	497,399

Source: Each year edition of *China Statistical Yearbook* and *Shanghai Statistical Yearbook*.
Note: Column of "Private" indicates the number of vehicles owned by individuals.

Table 3 Automobile (civil vehicle) and motorcycle ownership in Shanghai, 2001-2008

unit: 10 thousand

		2001		2002		2003		2004	
			Private		Private		Private		Private
Automobile		55.01	8.72	62.30	14.68	71.90	22.44	83.51	31.77
Detail	Passenger Vehicles	37.19	8.40	45.09	14.36	54.03	22.13	64.69	31.47
	Cars	24.05	6.68	29.37	10.79	36.16	16.66	44.60	24.28
	Freight Trucks	15.98	0.32	17.21	0.31	17.87	0.31	18.82	0.30
Motorcycle		62.75	58.73	74.09	70.07	98.46	94.29	113.85	109.87
		2005		2006		2007		2008	
			Private		Private		Private		Private
Automobile		95.15	41.00	107.04	50.94	119.70	61.29	132.12	72.04
Detail	Passenger Vehicles	76.00	41.00	87.06	50.91	98.92	61.25	110.73	71.99
	Cars	53.59	32.21	62.81	40.95	72.81	50.15	82.96	59.69
	Freight Trucks	19.16	0.04	19.98	0.03	20.78	0.04	21.39	0.05
Motorcycle		120.42	116.52	124.15	120.13	125.97	122.20	127.37	123.82

Source: Each year edition of *Shanghai Statistical Yearbook*.

Note: Column of "Private" indicates the number of vehicles owned by individuals.

Table 4 Comparison between the increase in individually owned passenger cars and the number of plates issued under the license plate auction system

Year	The increase in individually owned passenger cars (ten thousand) (A)	The number of plates issued passenger cars owned by individuals and private-sector companies （B)	B/A （%)	The percentage of passenger cars in total vehicles owned by individuals （%)
2002	4.11	31,850	77.49	73.50
2003	5.87	53,068	90.41	74.24
2004	7.62	71,600	93.96	76.42
2005	7.93	67,078	75.12	78.56
2006	8.74	64,500	83.33	80.39
2007	9.20	75,500	82.07	81.82
2008	9.54	84,500	88.57	82.86

Source: *Shanghai Statistical Yearbook*.

Note: For the source of the number of license plate issued, see:

< http://www.alltobid.com/guopai/ >(viewed on June 18, 2010).

Table 5 Comparison of Elasticity between Shanghai and Beijing

		Shanghai	R^2	Beijing	R^2
1988-1998		0.5498	0.8921	1.9746	0.9730
		(8.63)		(18.00)	
	1988—1993	0.8743	0.8265	2.0498	0.9402
		(4.36)		(7.93)	
	1994—1998	0.5087	0.7786	2.8786	0.9760
		(3.25)		(11.03)	
1999—2008		2.7426	0.8698	1.0083	0.9318
		(7.31)		(10.46)	

Source: Each year edition of *China Statistical Yearbook*.

Note: Elasticity is calculated by logarithm linear regression with time series data. The number in the brackets is t-value.

International cooperation between China and developed countries: promoting energy supply from west to east

Azusa Okagawa
National Institute for Environmental Studies
Kanemi Ban
Osaka University

Abstract

The Chinese government executes the West-East gas pipeline project as a part of the western development plan to solve social issues; expanding energy demand and air pollution in the east coastal region and regional gap between western and eastern China. If developed countries could suggest such international cooperation pushing these actions of Chinese government as well as energy intensity improvement, it might become a breakthrough agreement in prevention of global warming. We developed a multi-regional dynamic CGE model of China to evaluate international cooperation programs between China and developed countries with focusing on relative prices between energy, capital and other goods. The result shows that helping development of gas field in western China could promote natural gas supply from west to east and would improve regional gap.

Keywords: energy intensity, natural gas, regional gap, multi-regional dynamic CGE model

JEL classification: Q54, Q 56, Q42, D58

Corresponding author:
Azusa Okagawa
National Institute for Environmental Studies,
Onogawa 16-2, Tsukuba, Ibaraki, 305-8506 Japan
Email: okagawa.azusa@nies.go.jp

1. Introduction

China is the largest emitter of CO_2 in the world. Developed countries have been seeking to encourage China to participate in the future framework for climate change, but it is difficult to cap their emissions because they are worried about cost of emission reduction and they do not want to slow their economic growth. It is necessary not only to provide technological and financial assistance by developed countries but also to suggest attractive mechanisms which bring the simultaneous achievement of environment and economic growth to developing countries.

China has social distortions as a result of rapid economic growth in east coastal regions. Chinese economy highly depends on the coal fired power generation and the health damage caused by air pollution is a growing concern in the east coastal regions. As a result of focusing on economic growth in the east coastal regions, there is a wide income gap between urban and rural areas. One of the goals of the 11th Five-Year Plan from 2006 to 2010 is well-balanced development between efficiency, equity and income redistribution. Chinese government addresses environmental issues and demands for clean technology as a part of the balanced development.

We suggest developed countries to help fuel shift from coal to natural gas. China is endowed with natural gas in West and has a big project to transfer natural gas to east. Increase of natural gas share in China would reduce CO2 emissions per GDP and air pollution of SOx and NOx. However, infrastructures to supply natural gas are not sufficient and the relative price of natural gas is quite higher than that of coal. Therefore, there is less incentive of fuel shift.

The results of previous studies show that the change of relative user costs between fuels promotes fuel substitutions and the increase of aggregate energy price improves energy-GDP ratio in China. To create incentive for using western energy in East, the change of relative prices between eastern and western energy should be changed. Furthermore, to improve aggregate energy efficiency, relative energy price should be higher than other goods. Those points are indicated by the results of following literatures. Mao et al. (2005) is a case study on fuel substitutions in Chongqing and Beijing. It indicates that the higher user cost of natural gas including initial investment is an obstructive factor of fuel switch from coal to natural gas in Beijing and that allowing private and foreign investors' access to natural gas industry would solve the shortage of capital. Hang and Tu (2007) estimated the price elasticity of energy demand in China. They show energy-GDP ratio of China has been improved by increase of relative price of energy and indicate that raising energy prices might be an effective policy to improve energy efficiency.

In this study, we develop a multi-regional dynamic CGE model of China to evaluate international cooperation programs which improve the energy-GDP ratio and help those actions focusing on relative prices between energy, capital and other goods. Our result shows that helping development of gas field in western China could promote natural gas supply from west to east and would improve regional gap.

The remainder of this paper is organized as follows. Section 2 presents an overview of the present situation surrounding energy and environment in China. Section 3 illustrates the regional dynamic CGE model we developed and Section 4 shows simulation results. Section 5 concludes this study.

2. Present situation surrounding energy and environment

2.1 Present situation surrounding energy and environment

China is well endowed with coal resource and highly relies on it. However, energy demand is expanding for rapid economic growth and they face energy shortage in the east coastal region. At the same time, the health damage and acid rain caused by air pollution is getting a serious social issue. Small inefficient coal-fired power plants are closed and replaced by large and efficient power plants to improve energy efficiency and to reduce air pollution. The Chinese government is also promoting to use natural gas produced in western China, so called "the West-East gas pipeline project". They have natural gas resource in the western China and PetroChina leaded to construct the 4000km natural gas pipeline from the Tarim Basin to big cities in East coastal regions as Shanghai. They build infrastructures for stable energy supply and sustainable economic growth.

The West- East gas pipeline project is a part of the western development plan. The regional gap between the eastern and western China is also a serious social issue. To correct it, they introduced policies to invite the foreign capitals in western regions and build railways in the southwestern regions.

2.2 Factors to contribute CO_2-GDP ratio improvement

The climate policy requires reducing CO_2-GDP ratio at least. The improvement of CO_2 emissions per GDP is decomposed to some factors by the Kaya's equation.

$$\frac{CO_2}{GDP} = \frac{CO_2}{Energy} \cdot \frac{Energy}{GDP} \qquad (1)$$

The first term of right hand side means CO_2 emissions per energy input and the second term means energy intensity.

The first term will be improved by fuel substitution, which means using natural gas more instead of coal to get the same amount of heat. The change of relative prices will induce fuel substitution. The user cost of natural gas is about four times as that of coal in Beijing[1]. The construction of gas pipeline would decrease the cost of natural gas input and it adds the incentive to increase it instead of coal.

China has less incentive not only to substitute expensive natural gas for cheap coal, but also to introduce highly efficient equipment. The second term will be improved by change of industrial structure and introduction of energy-saving equipments. For example, Japan is resourceless and energy cost is higher. They have large incentive to introduce highly-efficient equipments to save energy. However, China is well endowed with energy resource and has access to it at cheaper price. Consuming energy is cheaper to introducing energy-saving equipment which is expensive. To induce introduction of energy-saving equipment, decreasing capital price compared to energy price would be effective by foreign investment.

3. Policy Simulation using a regional dynamic CGE model

3.1 Simulation scenario

To analyze the effect of changing relative prices between energy from different regions and between energy and capital, we prepared three simulation scenarios.

(1) Capitalizing in all industries of both regions

(2) Energy development in West

(3) Pipeline construction

Under the scenario (1), we consider the developed countries capitalize in industries for improving energy efficiency. This means developed countries provide Chinese industries with high efficiency technologies. We assume that the capital in china increase by 5% and it brings 20% of energy efficiency improvement. Under the scenario (2), developed countries capitalize in the energy industry of the West, which means that they fund developing gas fields in the West. It makes the natural gas extraction in the West easier and they use it more instead of coal in the East. We assume that they concentrate the same amount of investment as scenario (1) on an energy industry of the West. The scenario (3) is construction of pipelines case. Under this scenario, developed countries help transportation cost of natural gas from the West to the East. It induces substitution between the energy from the West and the energy from the East in industries of the East. We assume that the

[1] Mao et al. (2005)

input cost of energy produced in West is reduced by 25% due to subsidizing by developed countries.

3.2 Model and data

We developed a multi-regional dynamic CGE model for the Chinese economy. Representative households of regions purchase goods and services by providing firms with labor and capital. Households' demands are derived from the utility maximization problem and they have Cobb-Douglas utility functions. Firms produce goods and services using labor, capital and intermediates inputs. Firms' demands for goods and production factors are derived from the cost minimization problem and they have nested-CES production functions.

Labor and capital are movable between industries, but unmovable between regions. China exports goods and services to foreign countries and imports goods and services from abroad. The balance of payment is exogenous and the exchange rate is endogenous. The substitution between domestic goods and imported goods are determined by Armington's assumption.

This model is based on the dynamic optimization developed by Ramsey and describes optimal growth path. Once a policy shock is given, the economy moves to a different steady state through a different growth path. This model can explain the economic impact of policy change; regional GDP paths, Industrial output in each area, relative prices among goods and production factors. Annual GDP growth rates are 8% in both areas. We solve the model from 2000 to 2050.

We used a regional IO table of China developed by the IDE-JETRO[2]. We aggregated eight regions to two regions. (Table 1) The GDP of the East is four times as that of the West. The GDP per capita of the East is twice as that of the West. In our model, we aggregated 30 industries into four; agriculture, energy, manufacturing and service. In the East the manufacturing industry has a big share.

The Chinese economy depends on energy produced by the eastern energy industry as a whole. The industries in the East use the energy produced in the East and the industries in the West use the energy produced in the West. (Fig.1, 2) The West is endowed with abundant natural gas and now they are developing gas fields and pipelines to transport gas from the West to the East. Inducing the natural gas use instead of the coal would reduce CO_2, SOx and NOx emissions in industrialized cities.

The manufacturing industry in the West is more energy intensive than that in the East. The agriculture, energy and service industries in the West are less energy intensive than

[2] IDE-JETRO (2003)

that in the East. (Table 4)

Table 1 Regional aggregation

Original regions	Mapping
North East	East
North Municipalities	
North Coast	
Central Region	
Shouth Coast	
North West	West
Shouth West	

Table 2 Industrial aggregation

No	Original industry	Mapping	Symbol
1	Agriculture	Agriculture	agr
2	Coal mining and processing	Energy	ene
3	Crude petroleum and natural gas products	Energy	ene
4	Metal ore mining	Manufacturing	mfg
5	Non ferrous mineral mining	Manufacturing	mfg
6	Manufacture of food products and tobacco processing	Manufacturing	mfg
7	Textile goods	Manufacturing	mfg
8	Wearing apparel and related products	Manufacturing	mfg
9	Sawmills and furniture	Manufacturing	mfg
10	Paper and related products	Manufacturing	mfg
11	Petroleum processing and coking	Manufacturing	mfg
12	Chemicals	Manufacturing	mfg
13	Nonmetal mineral products	Manufacturing	mfg
14	Metals smelting and pressing	Manufacturing	mfg
15	Metal products	Manufacturing	mfg
16	Machinery and equipment	Manufacturing	mfg
17	Transport equipment	Manufacturing	mfg
18	Electric equipment and machinery	Manufacturing	mfg
19	Electric and telecommunication equipment	Manufacturing	mfg
20	Instruments meters cultural and office machinery	Manufacturing	mfg
21	Maintenance and repair of machine and equipment	Manufacturing	mfg
22	Other manufacturing products	Manufacturing	mfg
23	Scrap and waste	Manufacturing	mfg
24	Electricity steam and hot water supply	Energy	ene
25	Gas production and supply	Energy	ene
26	Water production and supply	Service	srv
27	Construction	Service	srv
28	Transport and warehousing	Service	srv
29	Wholesale and retail trade	Service	srv
30	Services	Service	srv

Table 3　Social Accounting Matrix in 2000

billion yuan		East agr	East ene	East mfg	East srv	East hhld	East govt	East inv	West agr	West ene	West mfg	West srv	West hhld	West govt	West inv	All exp	All imp	All disc	Total
East	agr	270	4	549	58	785		41	3	0	3	0	7		0	39	-37	140	1863
East	ene	20	107	473	105	48			1	2	9	1	1			34	-43	-103	654
East	mfg	338	133	4774	1580	1485		625	22	6	125	74	88		33	1250	-1085	-76	9370
East	srv	137	98	1186	1072	718	684	1391	2	2	18	15	8		1	261	-72	-573	4951
West	agr	3	0	5	1	8		0	93	0	123	12	282		17	2	-3	60	605
West	ene	0	5	15	1	0			5	18	81	17	9			1	0	-15	136
West	mfg	6	2	107	33	25		8	67	14	409	254	274		78	54	-42	46	1336
West	srv	4	3	21	8	3		0	28	21	186	219	156	188	305	11	-2	-82	1070
Vadd	taxi	28	39	503	274				16	7	103	55							1024
Vadd	Labor	974	117	1086	1157				324	30	174	292							4154
Vadd	Capital	82	145	651	661				44	36	106	132							1857
	Total	1863	654	9370	4951	3072	684	2067	605	136	1336	1070	824	188	436	1651	-1284	-604	

Unit: billion yuan

agr: agriculture, ene: energy, mfg: manufacturing, srv: service

Table 4　The feature of industries in the West and the East area

	Agriculture		Energy		Manufacturing		Service	
	West	East	West	East	West	East	West	East
Capital/Labor	0.14	0.08	1.22	1.23	0.61	0.60	0.45	0.57
Cost share of energy	0.9%	1.1%	14.5%	17.2%	6.7%	5.2%	1.7%	2.1%

Note: “Labor/Capital” ration means the labor input cost divided by the capital input cost. “Cost share of energy” stands for the energy input cost divided by the output value.

Fig.1　Energy input share of western industries

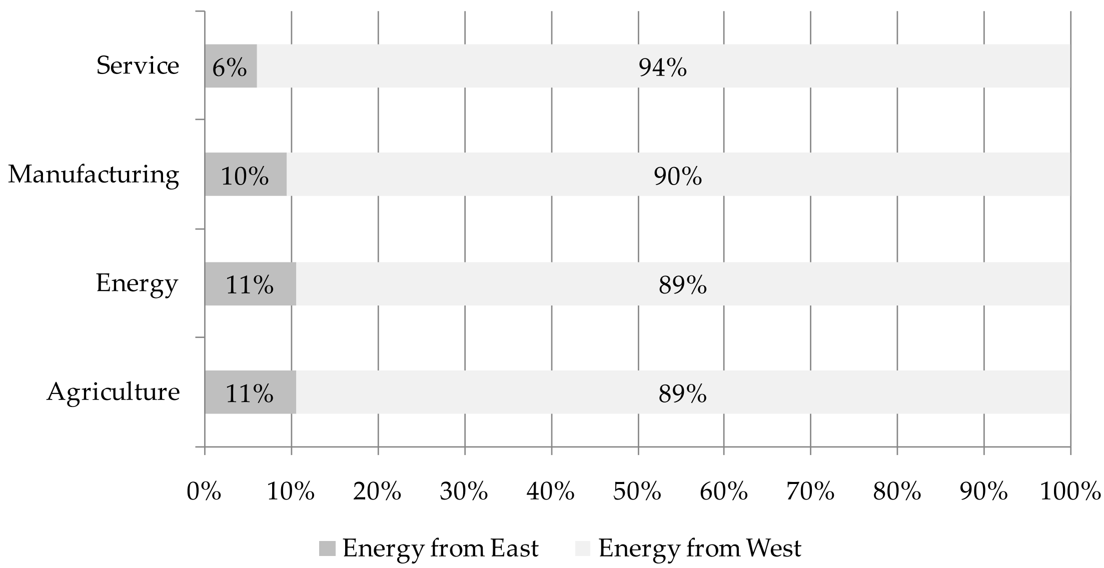


Fig. 2   Energy input share of eastern industries

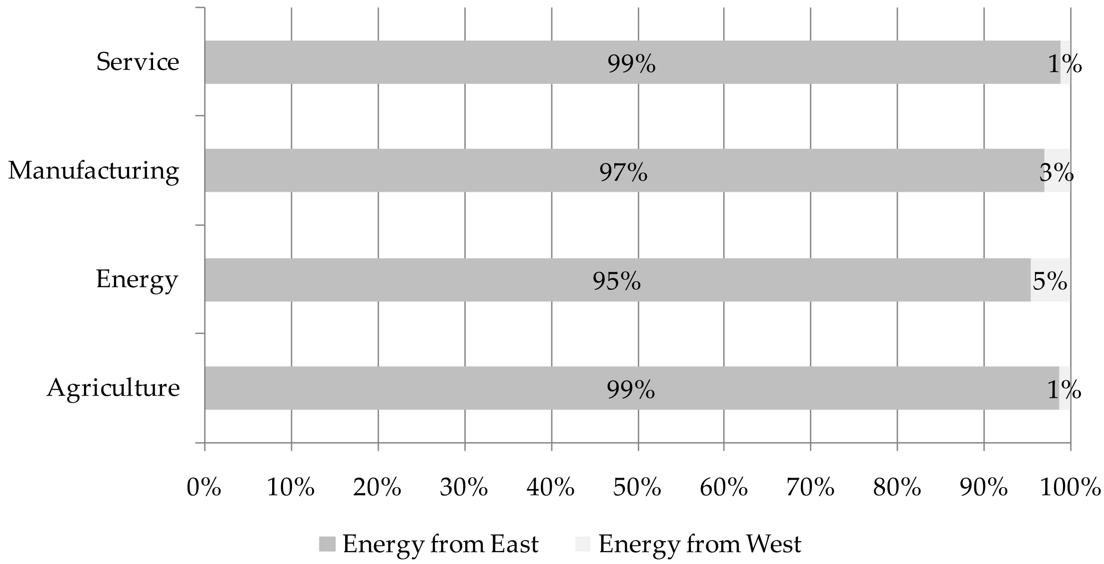


Fig. 3   Industrial structure of the West and the East areas

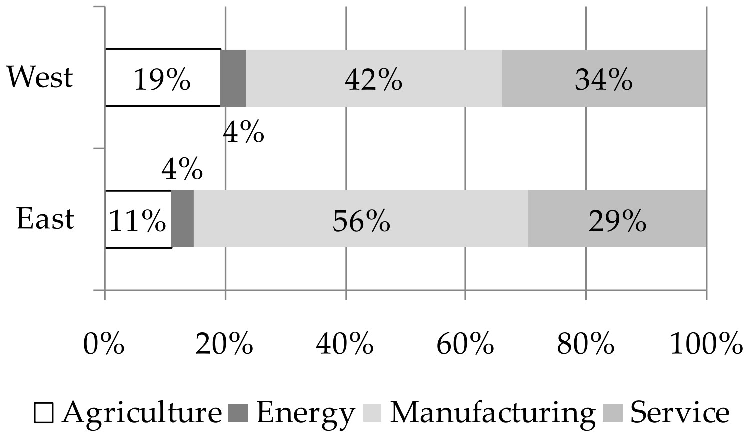
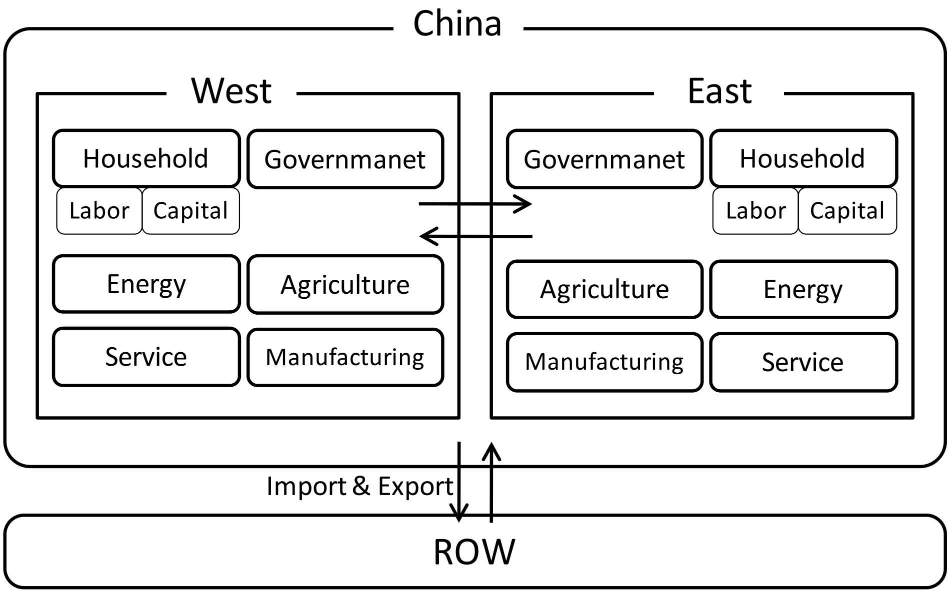


Fig. 4 Overview of the multi-regional dynamic CGE model of China



4. Simulation result

4.1 Simulation result

Table 3 shows macro economic impacts. The energy development in West scenario is most effective to improve E/GDP. Under this scenario, capital price became cheaper compared to energy, industries input capital more and energy was saved. Under the first scenario, the relative price of energy to capital increased, but Energy/GDP did not improve. Capitalizing in all industries of both regions brings expansion of the Chinese economy and it creates bigger energy demand than energy-saving. Reduction of Energy transportation cost decreases PE/PK because of subsidies by developed countries, but Energy/GDP ratios would not change. Subsidizing of input of energy produced in West just promotes energy substitution and it would not decrease energy demand. Regional gap would shrink in the Capital in energy of West scenario[3].

Fig. 4 shows industrial output change from BAU under the scenario (1). Energy output increased significantly. Other industries need to produce more and they raised up the energy demands. Increase of energy industries in the West is bigger than that in the East where the production cost o f energy is relatively expensive.

Under the scenario (2), energy demand decreased. (Fig. 5) They switch the energy from

[3] We calculated regional populations in 2015, 2020 and 2030 based on the population prospects at province level in Shen (1996).

the East to that of the West, which means the coal is substituted by the natural gas. The relative energy price to the capital increased and the output of manufacturing which is energy intensive decreased. The agriculture and service are labor and capital intensive, so their output level increased.

Helping transportation cost of natural gas from the West to the East is effective to substitution between the natural gas and the coal. (Fig. 6) Cheaper transportation cost of energy raise up the output levels of industries, especially of the manufacturing industry in the West.

Table 3 Macro economic impacts

		(1) Capitalizing in all industires of both regions			(2) Energy development in West			(3) Pipeline construction		
		West	East	Total	West	East	Total	West	East	Total
GDP	2015	1.67	0.22	0.52	5.91	-2.84	-1.05	0.39	0.04	0.11
	2020	1.78	0.38	0.66	6.19	-2.97	-1.10	0.40	0.05	0.12
	2030	2.11	1.03	1.25	5.73	-3.55	-1.65	0.39	0.05	0.12
E/GDP	2015	6.06	5.63	5.61	-5.69	-2.41	-3.41	0.00	0.00	0.00
	2020	6.29	5.83	5.82	-5.13	-2.66	-3.55	0.00	0.00	0.00
	2030	7.76	7.44	7.43	-6.63	-4.07	-4.98	0.00	0.00	0.00
PE/PK	2015	2.52	2.99	-	59.01	0.04	-	-5.35	-0.13	-
	2020	2.69	3.08	-	62.17	-0.60	-	-5.20	-0.09	-
	2030	4.82	5.64	-	61.36	-2.95	-	-5.13	-0.07	-

Table 4 Regional gap (GDP per capita)

	2015	2020	2030
	West East	West East	West East
(0) BAU	1.00 : 1.53	1.00 : 1.54	1.00 : 1.56
(1) Capitalizing in all industries of both regions	1.00 : 1.51	1.00 : 1.52	1.00 : 1.54
(2) Energy development in West	1.00 : 1.40	1.00 : 1.40	1.00 : 1.42
(3) Pipeline construction	1.00 : 1.52	1.00 : 1.53	1.00 : 1.55

Fig. 4　Industrial output in the scenario (1)

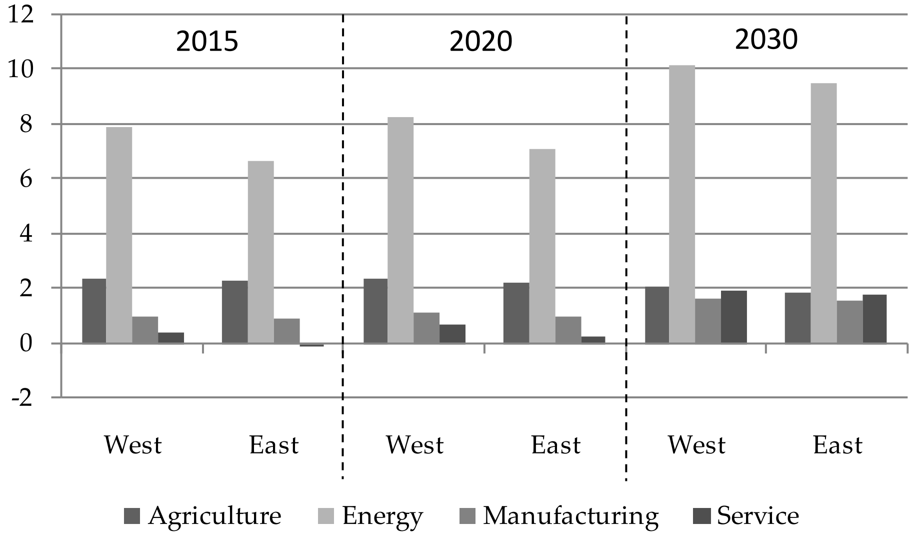


Fig. 5　Industrial output in the scenario (2)

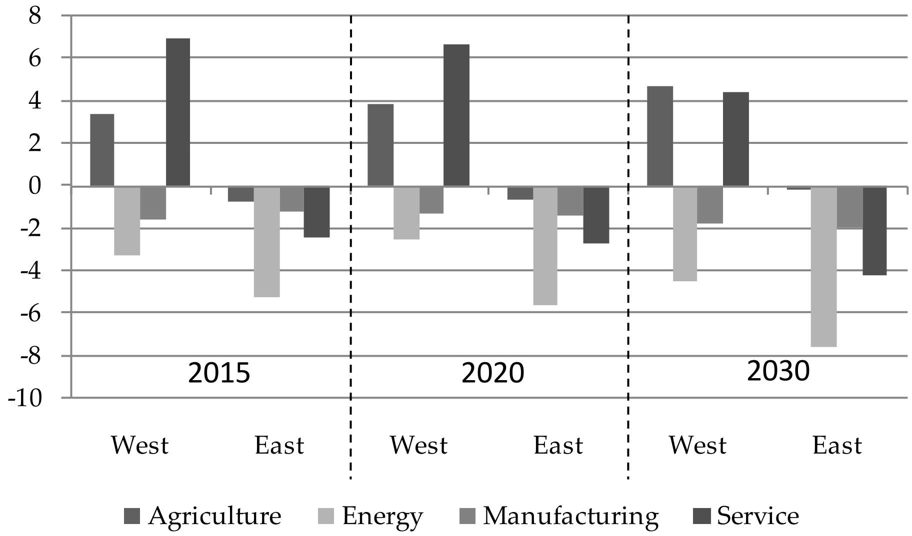
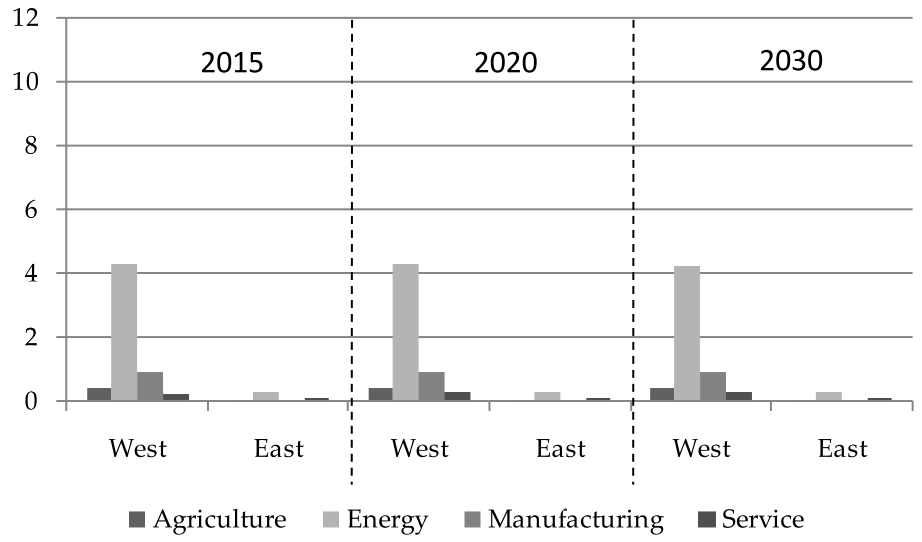


Fig. 6 Industrial output in the scenario (3)



4.2 Factor analysis of CO_2/GDP improvement

We decomposed the factors of our results which contribute for CO_2 emissions per GDP following the Kaya's equation (1).

$$\frac{CO_2}{GDP} = \frac{CO_2}{Energy} \cdot \frac{Energy}{GDP} \qquad (1)$$

The first term of (1) is brought by fuel shift to the fuel including less carbon content. The second term is promoted by introducing energy-saving equipments and industrial structural change. Table shows the contributors for the CO2/GDP improvement under the three scenarios.

Under all scenarios demand for energy produced in West would be increased, which implies that fuel shift will occur in China from coal to gas. So the first term of equation (1) will be improved and we can expect these programs to reduce other air polluting gas as SOx and NOx.

Capitalizing in all industries of China would stimulate energy demand by expanding of Chinese economy, so the energy-GDP ratio would become worse. Pipeline construction would help transportation of energy from West to East and industries in East would use energy produced in West more. However, total energy demand of China will not change and the energy-GDP ratio would not improve.

Table 5 Decomposition of contributors

	$\frac{CO_2}{Energy}$	$\frac{Energy}{GDP}$
(1) Capitalizing in all industries of both regions	-	+
(2) Energy development in West	-	-
(3) Pipeline construction	-	0

5. Conclusion

To induce fuel shift from coal to natural gas in China, focusing on the west area of China is effective. If developing countries set up a carbon fund by developed countries, it would help the energy-efficient technology diffusion in China.

Energy development in West could bring low carbon society in China through inter fuel substitutions. It also would improve the regional gap between West and East areas in China. Developed countries including Japan could buy carbon credit with lower cost and they would receive higher capital return. Encouragement of investment and the spread of technology by Chinese and Japanese governments would bring sustainability to both countries.

Acknowledgement

We would thank members of the subcommittee of environmental cooperation between China and Japan, ESRI. We also thank Prof. Zhou Hongchun, Prof. Chen Changhe and Dr. Feng Shengbo who gave valuable comments at the workshop of environmental cooperation between China and Japan at Beijing. All remaining errors are ours.

References

IDE-JETRO (2003) Multi-regional Input-Output Model for China 2000, Institute of Developing Economies, Japan External Trade Organization.

Hang, L., and Tu, M. (2007), The impacts of energy prices on energy intensity: Evidence from China, Energy Policy 35, 2978-2988.

Mao, X., Guo, X., Chang, Y., Peng, Y., (2005), Improving air quality in large cities by substituting natural gas for coal in China: changing idea and incentive policy implications, Energy Policy 33, 307-318.

Shen, J. (1996) Internal migration and regional population dynamics in China. Progress in Planning, 45, 123-188.

The First EAAERE meeting on Environmental and Natural Resources Economics
in Hokkaido, Japan, 2010

How to sustainable use the reservoir with woody debris and turbidity current

Prof. Yih-Chi Tan[1], Prof. Jihn-Sung Lai[2]
Fong-Zuo Lee[3], Dr. Shuen-Jong Tsorng[4]

[1] Professor, Dept. of Bioenvironmental Systems Eng., NTU, Taipei City, 106, Taiwan, R.O.C., E-mail:yctan@ntu.edu.tw
[2] Research Fellow, Hydrotech Research Institute and Professor, Department of Bioenvironmental Systems Eng. , NTU, Taipei City, 106, Taiwan, R.O.C., Jslai525@ ntu.edu.tw
[3] Ph. D Candidate, Dept. of Bioenvironmental Systems Eng. , National Taiwan University(NTU), Taipei City, 106, Taiwan, R.O.C., E-mail:d94622004@ntu.edu.tw
[4] Postdoctoral Researcher, Hydrotech Research Institute, NTU., Taipei City, 106, Taiwan, R.O.C., E-mail:sjtsorng@hy.ntu.edu.tw

Abstract

The Shihmen reservoir is one of the most important reservoirs in the northern Taiwan, which is a multi-functional reservoir for irrigation, water supply, hydroelectric power, flood prevention and recreation. In 2004, the inflow of Typhoon Aere brought large amount woody debris with high sediment-laden flow into the Shihmen reservoir. Massive woody debris is been carried into the hydroelectric power intake to damage turbine seriously. Sediment concentration of the inflow water in Typhoon Aere rose up to 326,700 mg/L which was far-exceeded water treatment capacity. Such high turbid concentration caused water shortage for two weeks in the Taoyuan area where 2.4 million people live. Afterword, floating barriers had been built at upstream to trap woody debris. However, the flow-sediment interaction mechanism between turbidity current and woody debris motion has not yet been well understand. From field observations, we can learn more details between woody debris and turbidity current in the Shihmen reservoir. Finally, we need to sustainable use a reservoir is very important issues in the natural resources.

Key Words : woody debris, turbidity current, field observations.

1. INTRODUCTION

Taiwan is situated at a geographical location with special climatic condition that brings to the island 3.6 typhoons per annum on the average. These typhoons often result in flood disasters that can cause serious damage to properties and sometimes with severe casualties. On the other hand, when typhoon or heavy rain fall occurs in Taiwan, the watershed may generate amount of sediment yield. And, land development in the watershed could accelerate soil erosion. As sediment moves into a reservoir, deposition occurs due to decrease of velocity. In general, the large size sediment may deposit quickly to form delta near the backwater region tail. The hydraulic phenomenon of delta area is similar to the shallow water of open channel. The inflow sediment presents two patterns, bed load and suspended load. The bed load may deposit at the front set of delta, and the suspended load may flow through the delta and deposit by sorting. When turbid inflow continues to move, the turbulence energy decreases by resistance. The inflow may plunge into the reservoir to develop turbidity current and move toward downstream. At plunge point, the water near the surface in the reservoir can flow toward upstream due to continuity behavior of the flow. Figure 1 illustrates the flow phenomenon of density current and trapped debris.

Many flume experiments and field measurements have shown that the occurrence of the turbidity current at plunge point can be related to velocity, depth and fluid density before plunge point (Graf 1983). In 2004, Typhoon Aere attacked north Taiwan. The Shihmen reservoir water supply suffered from a shortage of water supply for 14 days in the Taoyuan area where 2.4 million people live. The watershed of Shihmen reservoir is shown in Figure 2. The Figure 3 shows that woody debris distribution was near the dam site after Typhoon Aere. In the figure, massive woody debris floated and got trapped in front of the dam. The extraction volume was about 5.4×10^5 m^3. The field survey shows that when power plant was operation, the turbine was damaged by woody debris that was carried into the hydroelectric power intake by flow to clog up the facilities (as shown in Figure 4).

This study presents the annual extraction volume of woody debris from 2004 to 2008 in which had typhoons with heavy rainfall. A regressed formula was used to estimate the volume of woody debris. The plunge point variation was been calculated by an empirical formula. The mechanism between woody debris and turbidity current was preliminary discussed through field observations.

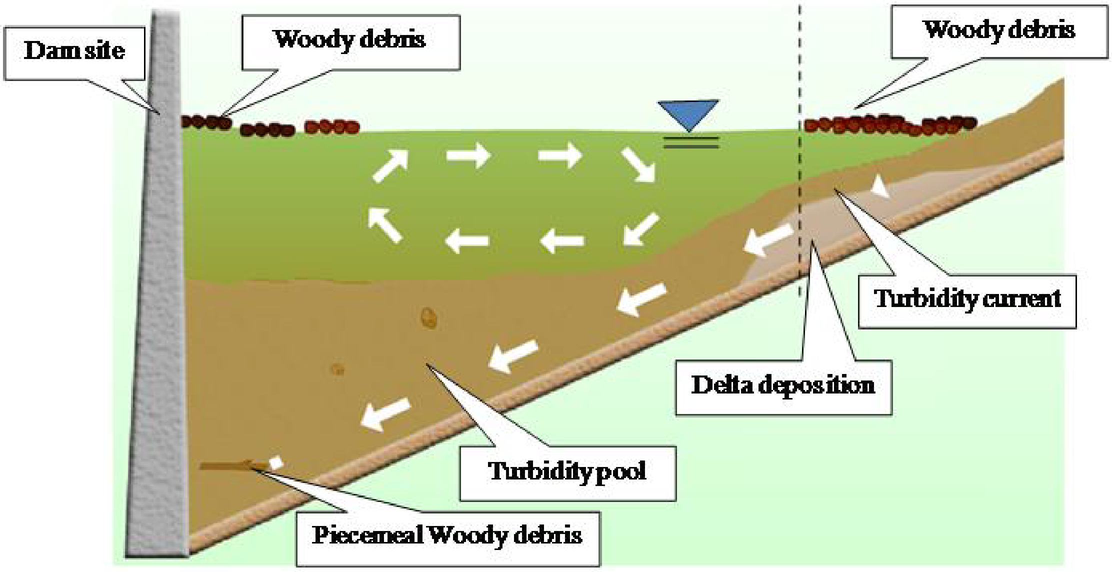


Fig. 1 Relationship between woody debris and turbidity current

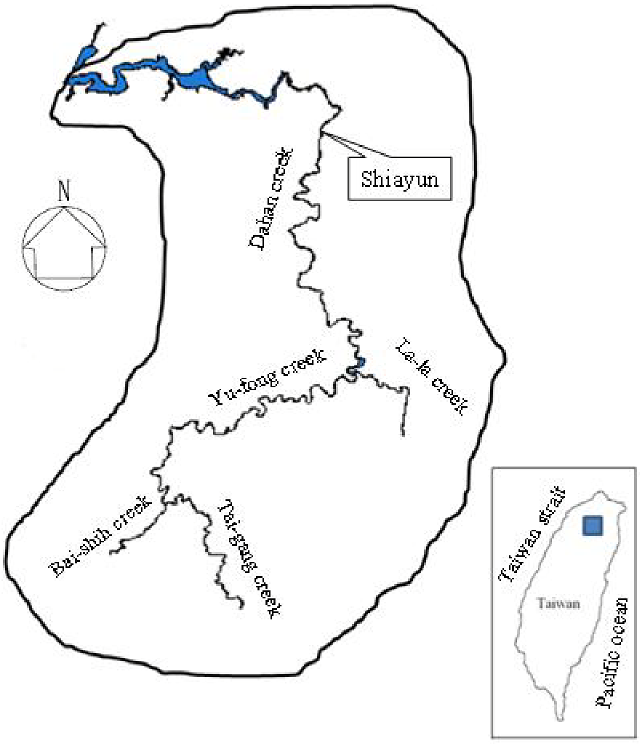


Fig. 2 Watershed area of Shihmen reservoir [3]

Fig. 3 The woody debris of Typhoon Aere [6]

Fig. 4 The turbine was clogged with woody debris [6]

2. Site Description

The Shihmen reservoir is a multi-functional reservoir and its functions include irrigation, water supply, generating electric power, preventing flood and recreation. The irrigation districts include Taoyuan, Hsinchu and Taipei for a total of 3.65 $x10^8$ m^2. The reservoir supplies drinking water to 28 districts and 3.4 million people. It is a very important water resource for the livelihood of the people in the northern Taiwan. Making use of the water impoundment at Shihmen dam, the Shihmen Power Plant generates 2.3 hundred million KWH (kilowatt per hour) annually, a vital contribution to help electric power demand and industrial development at rush hour. The reservoir main function is to prevent flood during typhoon and heavy rain seasons.

The Shihmen reservoir has a natural drainage area of 762.4 km^2. It is formed by the Shihmen dam located at the upstream reach of the Dahan River. The Dahan River is one of the three tributaries of the Tamshuei River which flows westward the Taiwan Strait. A map of the watershed area of the Shihmen reservoir is presented in figure 2. The Shihmen dam was constructed in 1963 is a 133.1m high embankment dam with spillways, permanent river outlet, power plant intake and flood diversion tunnels controlled by tailrace gates. The elevations of the spillway crest, permanent river outlet, power plant intake and flood diversion tunnels are EL.235 m, EL.169.5m, EL.173m and EL.220m, respectively. The total discharge of spillways is 11,400 m^3/s, permanent river outlet is 34 m^3/s, power plant intake is 137.2 m^3/s and flood diversion tunnels is 2,400 m^3/s. With a maximum water level of EL.245 m, the reservoir pool is about 16.5 km in length and forms a water surface area of 8.15 km^2. The initial storage capacity was 30,912x 10^5 m^3, and the active storage was 25,188x 10^5 m^3. Due to a lack of sufficient desiltation facilities, incoming sediment particles have settled down rapidly along the reservoir since the dam was completed. Based on the survey data, the Shihmen reservoir has accumulated a significant amount of sediment after dam completion. The depositional pattern has become wedge-shaped since 2000. From recent survey data in 2007, the storage capacity was estimated to be 69.28% of its initial capacity.

3. Woody debris

Woody debris is a structure element of river systems, which provides habitats for aquatic communities in the mountain area. But, due to steep slope and rain fall intensity, turbid inflow discharge is often supplied with dead trees coming from the watershed of reservoir. In 2004, the inflow discharge of Typhoon Aere brought large amount woody debris with high sediment concentration into the Shihmen reservoir. Massive woody debris was carried into the reservoir and drifted into power intakes to damage hydroelectric power generation facilities. The extraction volume was about 5.4×10^5 m^3. In addition, sediment concentration of the inflow water in Typhoon Aere rose to 326,700 mg/L which was far-exceeded water treatment capacity. Such high turbidity water leads to water shortage for two weeks in the Taoyuan area where 2.4 million people live. In 2005, as Typhoon Haitang, Matsa and Talim attacked

Taiwan, it resulted in 2 $\times 10^5$ m^3 extracted volume of woody debris, as shown in figure 5. Based on empirical formula of Rhone's river in winter presented by Moulin (2004), the inflow volume of woody debris can be estimated by inflow peak discharge. The assessment volume of woody debris during Typhoon Aere is about 6×10^5 m^3 which is closed to field extraction volume (5.4×10^5 m^3). According to taxonomic genus, most floating pieces belong to conifer and sinking pieces belong to broad-leaved tree. Based on filed survey, the floating pieces include Chamaecyparis formosensis, Calocedrus formosana, Cunninghamia lanceolata and Cryptomeria japonica. And, the sinking pieces include Cyclobalanopsis gilva, Cinnamomum camphora, Michelia formosana and Alnus formosana. Because of the different hydrological and morphological characteristics, the empirical formula needs to adjust by historical data of Shihmen reservoir. Therefore, the empirical formula does not apply to assess the woody debris volume of typhoon from 2005 to 2008. The annual woody debris was decreasing against the time. From 2006 to 2008, the extracted volume of woody debris was about 15,000 m^3, 10,000 m^3 and 5,000 m^3, respectively. Even though this tendency, the floating barriers had been installed at upstream at section 24 and section 27 to prevent woody debris into the reservoir area by Shihmen reservoir government (Young 2008). The conceptual idea is assumed that inflow woody debris flowing with turbid inflow and its flow mechanism is related to turbid inflow. Therefore, the floating barriers were established at upstream before turbid inflow plunged into reservoir bottom.

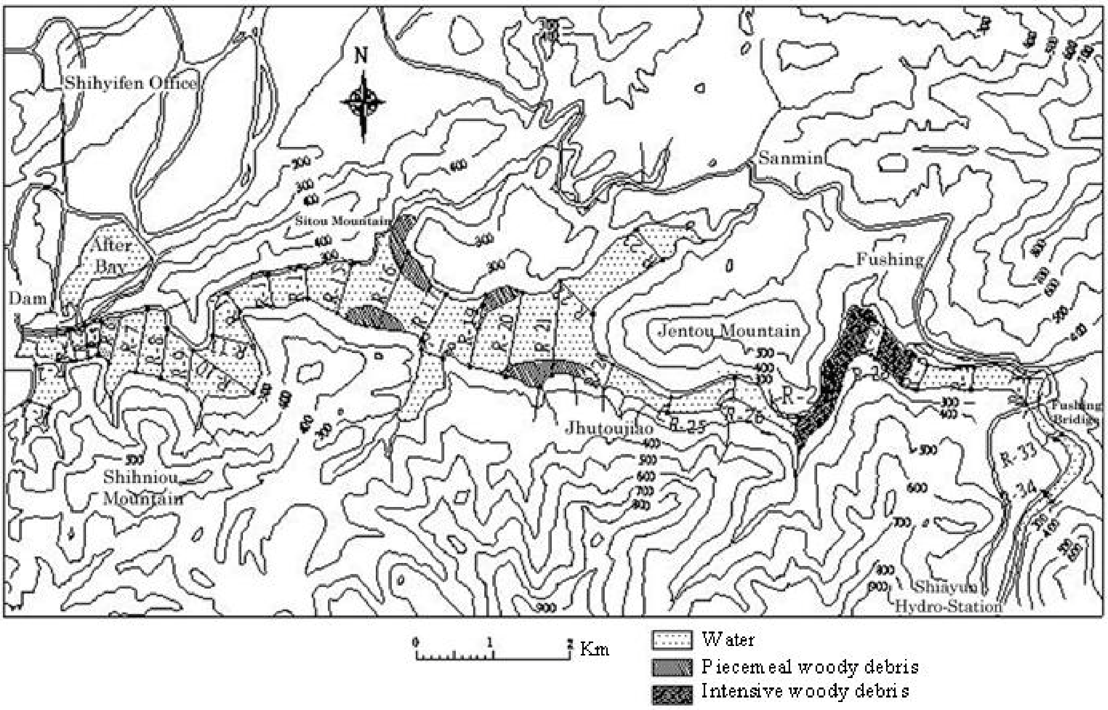


Fig. 5 Distribution of woody debris in Aug. 11 of 2005 after Typhoon Haitang and Typhoon Matsa [6]

4. Turbidity current

As mentioned before, in order to prevent woody debris flowing with turbidity current and plunge into the reservoir bottom, the plunge point of turbidity current should be estimated. Therefore, the objective of this component was to calculate plunge point evolution by means of an empirical equation with inflow hydrology. The following equation is an empirical formula in calculating plunge point (Lee and Yu 1997).

$$\mathrm{V_o} = \mathrm{F}_{rd}\sqrt{\frac{\Delta\gamma}{\gamma'}\mathrm{g}\mathrm{h_o}}$$

where $\mathrm{V_o} =$ average velocity of plunge point ; $\Delta\gamma = \gamma' - \gamma_0$; $\gamma' =$ specific gravity of turbidity current ; $\gamma_0 =$ specific gravity of fluid current ; $h_0 =$ water depth of plunge point ; $g =$ gravitational acceleration ; $\mathrm{F}_{rd} =$ densimetric Froude number.

Based on the continuous field measurement, the suspended sediment concentration in Shihmen reservoir could be linked to the discharge by following formula:

$$Q_s = aQ^m = 0.00257Q^{2.08} \qquad R^2 = 0.801$$

where a , $m =$ empirical rating coefficients ; $Q_s =$ suspended sediment concentration (kg/sec) ; Q = inflow discharge (m^3/s). According to Mulder and Syvitsky (1995), for many rivers the rating exponent m are typically between 0.5 and 1.5, and if m is determined from daily averaged or instantaneous measurements, it can frequently reach 2. Figure 6 shows the hydrograph of inflow discharge and inflow concentration by mentioned formula. Then, the specific gravity of turbidity current can be estimated by this formula. On the other hand, according to cross section and water level, the average velocity of plunge point and water depth of plunge point can be estimated. Therefore, the densimetric Froude number of each section is calculated, as shown in figure 7. Figure 7 is the results of densimetric Froude number variation during Typhoon Jangmi and it shows that the variation of densimetric Froude number was changing with flow condition. At beginning of Typhoon Jangmi, the plunge position was between section 30 and section 29. Then, high turbidity current accompanied by increasing inflow discharge and forced plunge point moving to downstream. When peak inflow is coming, the plunge point was between section 27 and section 26. But, when inflow discharge was decreasing to instream-flow, the plunge point was between section 29 and section 27.

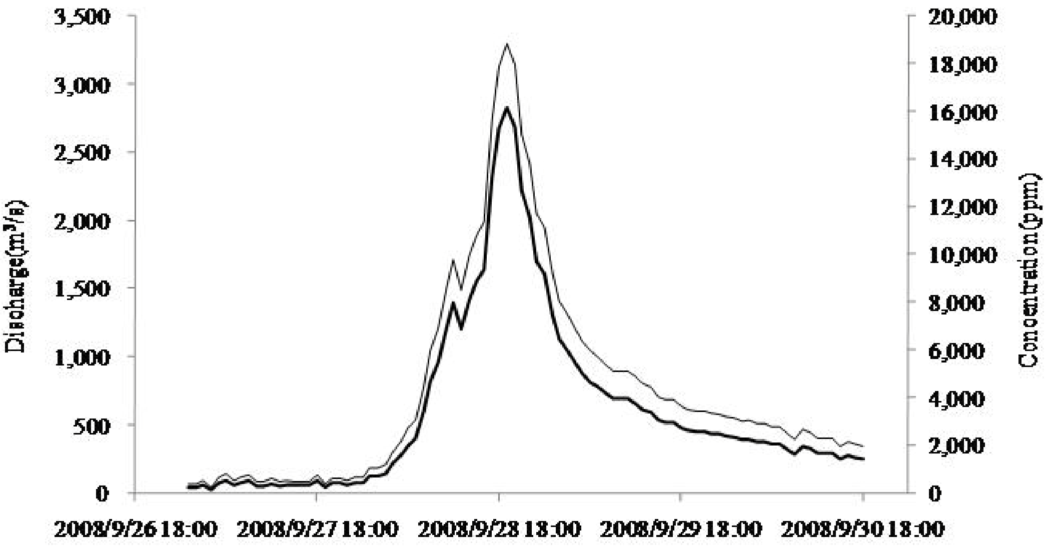


Fig. 6 Hygrograph of inflow discharge and concentration

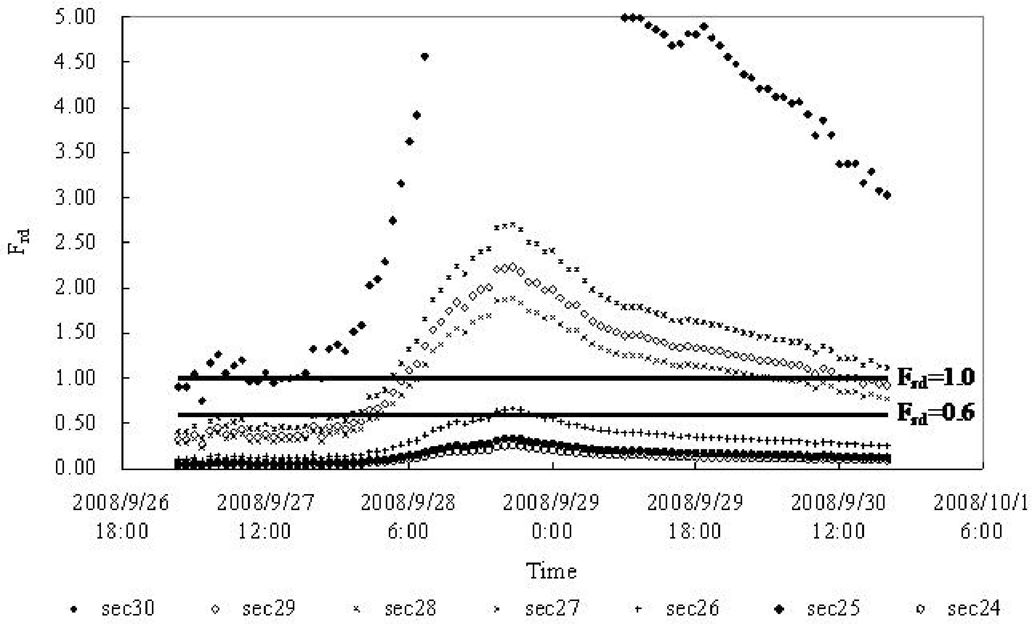


Fig. 7 densimetric Froude number variation during Typhoon Jangmi

5. Conclusions

Based on plunge point estimation of Typhoon Jangmi, the plunge point is not fixed. With increasing inflow discharge, the plunge point moves to downstream and with decreasing inflow discharge, the plunge point moves to upstream. According to the assessment, the plunge area was between section 30 and section 26, as shown in figure 8 and this result was closed to the position of intensive woody debris that had been shown in figure 5. The floating barriers had been installed at section 24 and section 27 in 2008 by Shihmen reservoir government to prevent woody debris into the reservoir area. The plunge point variation shows that during Typhoon and heavy rain, some woody debris would overflow the floating barrier at section 27 and some woody debris would plunge into the floating barrier at section 24. On the basis of densimetric Froude number simulation, the described situation probably happened. The figure 9 shows the woody debris location at section 24 after Typhoon Jangmi and confirms the description.

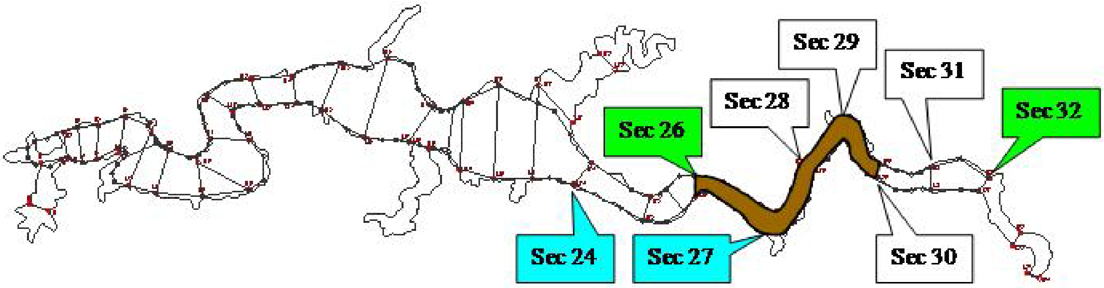


Fig. 8 Plunge point area during Typhoon Jangmi

Fig. 9 Woody debris location after Typhoon Jangmi at section 24

REFERENCES

[1] Graf, W. H., 1983 "The behavior of silt-laden current", Water power and dam construction, Vol. 35, No. 9, pp. 33~38.

[2] Lee, H. Y. and Yu, W. S., 1997 "Experiment study of reservoir turbidity current." Journal of Hydraulic Engineering, Vol. 123, No. 6, pp. 520-527.

[3] Moulin, B and Piegay, H., 2004 "Characteristics and temporal variability of large woody debris trapped in a reservoir on the river RHONE: Implications for river basin management", River research and applications, Vol. 20, pp. 79-97.

[4] Mulder, T., and Syvitsky, J. P. M., 1995 ''Turbidity currents generated at river mouths during exceptional discharges to the world oceans.'' J. Geology, Vol. 103, pp. 285–299.

[5] Young, D. L. and Lai, J. S., 2008 ''Driftwood motion and turbidity current in Shihmen Reservoir: experiments and analyses", Hydrotech Research Institute, NTU, Report No. 763(In Chinese).

Analysis of Subsidy Policy of China's Biomass Power Generation

Gao Li Mei Yingdan Ma Zhong Shi Lei
(School of Environment and Natural Resources, Renmin University of China, Beijing 100872, China)
(Email: gaoli0711@163.com)

Abstract

Biomass power generation is a kind of environmentally friendly renewable energy, which has a broad space for development in China. With the enaction of ***Renewable Energy Law***, the biomass power generation industry develops rapidly in recent years, and the installed gross capacity has made twice as much, but at the same time, most companies' state of operation is not very good. Because of varied reasons, such as cost, technology, and policy etc., most biomass power firms in a wide range of the country appear loss, and this industry is in the bottleneck. The subsidy policy, which is the core that this study will analyze systematically, is the primary mean of support of the biomass power generation. This study first introduces the current policy and law system of biomass power generation in China; then, generally evaluates the subsidy policy from several facets, like concept, operational mechanism, function and effect, and deeply analyses its advantages and weaknesses, based on the current development situation and existing problems of the biomass power industry; finally proposes some suggested improvements according to the results of above analysis.

Keywords

biomass power generation subsidy policy renewable energy policy analysis

1 Background

In recent decades, traditional fossil energy has not satisfied the energy demand of increasingly human need. In terms of power generation industry in China, thermal power generation plays a most significant role, but it also emits the most pollutants. Compared with thermal power generation, the pollution level of biomass power generation is relatively lower, more prominent environment benefits, and better development prospect. However, technology improvement and entrance to the market rely on more government investments and policy support. With the issuing and implementation of ***Renewable Energy Law*** in 2006, the Chinese government provides more and more policy support. To biomass power generation, it is mainly based on the price subsidy method. However, the development of biomass power generation industry in China encounters lots of problems and difficulties, such as high production cost, inadequate policy implementation, etc. Why do these problems occur? Whether price subsidy plays an important role in promoting the development of biomass power generation industry? The paper analyzes the price subsidy mechanism and relevant policies, tries to find the answers to the problems, and puts forward some improvement suggestions.

2 Framework of law and policy for China's biomass power generation

2.1 Policy support methods under the framework of Renewable Energy Law

With the total amount goal of installed capacity reaching 5.5 million kW in 2010 and 30 million kW in 2020 set by ***Long-term Development Planning of Renewable Energy*** and ***"11th Five-Year Plan" of Renewable Energy Development***, China supports the development of biomass industry by enforcing feed-in law to promise all the generating capacity of biomass in the net. On-grid price consists of every provincial benchmark price of desulfurization coal-firing units in 2005 and plus subsidy price ￥0.25/kW·h. And it promises that biomass power generation projects enjoy subsidy price for 15 years since starting production. Since 2010, every year's subsidy price of new approval construction programs will decrease by 2% over the previous year. Subsidy price and the expense of bridging network of renewable energy power generation projects will be paid by power grid companies, through levying renewable energy additional fees on electric consumers all over the country. In addition, special fund of renewable energy development has not provided any financial support for biomass power generation up to now.

So under the framework of ***Renewable Energy Law***, policy support of biomass power generation mainly depends on subsidy method. In fact, according to the material from National Development and Reform Commission, subsidy biomass power generation companies obtained every year includes provisional subsidy, bridging network subsidy, independent public power system subsidy and conventional ￥0.25/kW·h subsidy. Provisional subsidy has been carries out since 2007, which is based on ***Provisional Measures renewable energy power generation price and cost allocation management***. The subsidy standard is ￥0.1/kW·h based on the power capacity.

Functional subjects and operation methods of price subsidy policy of biomass power generation are presented below:

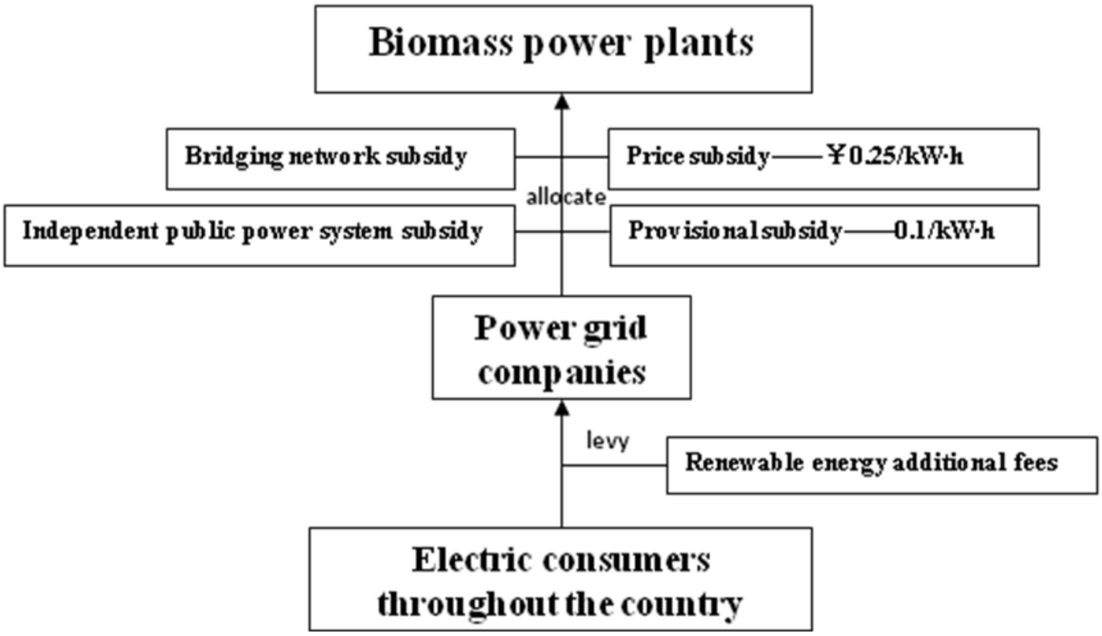


Figure 1 Mechanism of the biomass power generation subsidy policy

2.2 Other policy supports

Besides subsidy policy, Chinese government also implements other finance and taxation polices to support biomass power generation. But these policies are relatively scattered and support is limited. So far, finance and taxation polices related to biomass power generation have three types:(1) central government's environmental protection special fund; (2) preferential policies of value added tax; (3) preferential policies of income tax.

3 Current situation of China's biomass power generation industry

Since ***Renewable Energy Law*** was promulgated and implemented in 2006, biomass power generation industry develops rapidly. Many companies, such as China Energy Conservation and Environmental Protection Group, State Power Grid Company, 5 Power Generation Group and other large scale state owned enterprises, private enterprises, foreign-controlled businesses, actively participate in investment, construction and operation. And direct-combustion power generation industry develops most rapidly. National Bio Energy Co., Ltd invested and established biomass direct-combustion power plant in Shan County Shandong Province in December 2006. Until June in 2008, there were 18 biomass direct-combustion power plants built and put into operation, the total installed capacity of which reached 450 thousand kW. In addition, 70 programs have been approved and are under construction[1]. At the end of 2009, the total installed capacity of China's biomass power generation reached 4 million kW, which is double as much as that in 2005.

[1] Gao Hu, Wang Zhongying, Ren Dongming. *Knowledge Reader about Science, Technology and Industrial Development of Renewable Energy*, Chemical Industry Press, 2009, 273

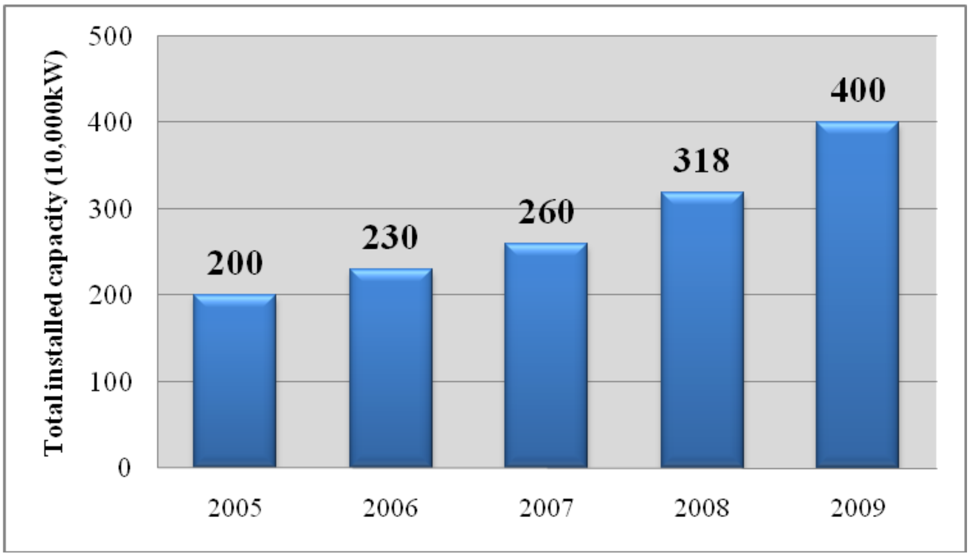


Figure 2 Total installed capacity of China's biomass power generation from 2005 to 2009[1]

However, as a renewable energy industry which is environmentally friendly and can increase farmer incomes, compared with solar power generation and wind power generation, biomass power generation has not caught enough attention. In recent years, biomass power generation bogs down because of high operation cost, inadequate market demand, technology, policy support, etc. According to the relevant reports, most of the biomass power generation companies have the difficulties in operation, and some plants can not normally operate during 60%-70% work time.

4 Analysis of subsidy policy of China's biomass power generation

4.1 Concept of subsidy policy of biomass power generation

Biomass generation subsidy policy is different from common fiscal subsidy. From the perspective of receptor, ￥0.25/kW·h is funds transfer from higher administrative unit, as revenue of biomass power generating enterprises, making the operating situation better, which truly satisfies the definition of subsidy policy. However, from the perspective of subsidy resource, these subsidy funds do not come from central finance, but power grid companies instead. Furthermore, those companies' funds used for the subsidies are not from state funds neither, but levying renewable energy additional fees on electric consumers, which means that large consumers virtually pay for these subsidies. In this sense, biomass generation subsidy is not a fiscal subsidy, but a kind of subsidy-like economic power price policy which is put forward to support biomass power generation industry.

This conceptive specialty of biomass power generation subsidy policy determines that its character and operating way are different from common fiscal subsidy; but its subsidy-like features make it have similar effects, advantages and disadvantages as other subsidy policies. Only by realizing these two points can we analyze and evaluate biomass power generation subsidy

[1] Data in 2005 come from *Renewable energy development long-term planning*; Data in 2006 and 2007 come from Shi Jingli, *Study on renewable power pricing mechanisms and price policies in China*, Electric Power, 2008(04); Data in 2008 and 2009 come from Energy Research Institute of National Development and Reform Commission.

policy completely and accurately.

4.2 Analysis of functional mechanism

As mentioned before, subsidy policy of biomass power generation are not related to central finance, and just undertaken all by power grid companies. This cost-sharing method essentially satisfies the principle of combination of national responsibility and citizen's obligation, which is emphasized by renewable energy law. Government is responsible for developing renewable energy, but those additional expenses, such as subsidy funds, from development and utilization process, have to be borne by whole people. By this way can we develop and utilize renewable energy on a large scale. In terms of biomass power generation, besides the energy value itself, it also has extra values—environmental and social benefits. The industry of biomass generation will benefit for partial and even all the national people. In this sense, establishing cost-sharing institution is reasonable.

However, to see from concrete functional mechanism perspective, this policy still remains some problems. Firstly, subsidy is a policy requiring huge amounts of money, no matter where it comes from, state or consumers. Power grid companies are not governments, and they do not have stable financial support, like the government, neither the right to charge subordinate companies with expenses. Developing biomass is a kind of state's duty, and only the government has the functions to tax or charge, but now the government has transferred this heavy duty to a grid power company, only a state-owned enterprise. Although the law gives the power to the company, the roles inversion between government and enterprises will be a potential hidden defect, which will surely influence the policy implementation in the long term. In addition, for electric consumers, renewable energy additional fees are an extra expense, which is equivalent to increase tax burden. In the case that other tax items are not adjusted, unilateral increasing new tax may lead to price rise. Furthermore, with the growth of biomass generating capacity, the amount of subsidy will also increase, as well as the burdens of enterprises. In the long term, the risk of inflation exists.

4.3 Evaluation of the policy effect

As a principal policy support method, subsidy policy has done a great deed for the development of China's biomass power generation industry in recent years. However, we cannot therefore believe that such policy is the most efficient. Besides the growth of total installed capacity, whether it has promoted the technologies of biomass power generation or not is another point for us to judge the subsidy policy's efficiency. But according to existing data and reports, no evidence is provided to verify the fact that biomass power generation technology has developed notably, or the production efficiency of biomass power plants has been raised dramatically in recent years, while lots of reports about biomass power plants facing severe bankrupt poured in.

Moreover, when total biomass installed capacity doubles, subsidies are also keeping a rapid growth in recent years. (See Table 1)

Table 1 Subsidy amounts of biomass power generation from 2006 to 2009 (Unit: 10,000Yuan)

Year	Amount of price subsidy (Including provisional subsidies)	Amount of bridging network subsidy	Total
2006	2474.3	0	2474.3
2007	42699.4[1]	764.7	43464.1
2008	89995.8[2]	2009.1	92004.9
2009[3]	82030.7	1935.8	83966.5

Source: collected and calculated according to National Development and Reform Commission

It can be seen from Table 1, supposing the total amount of subsidies in 2009 is calculated as twice as that from January to June, the total amount of subsidies are highly increasing to about 1.66 billion Yuan in 2009, from 24.74 million Yuan in 2006, a hike of nearly 70 times. Given that the subsidy policy is just enacted and most of the plants are under construction in 2006, the subsidies amount in that year is relatively lower. Although we calculated the total amount from 2007, it still increased by 3 times in two years, far more rapidly than biomass installed capacity.

To see from another data—total amount of provisional subsidies, things are looking worse. (See Table 2)

Table 2 The number of plants gained provisional subsidies and the total amount of provisional subsidy from 2006 to 2009

Period	Quantity	Amount of provisional subsidy (10,000 Yuan)
2006	0	0
Jan. 2007-Sep. 2007	6	3114.0
Oct. 2007-Jun. 2008	21	12466.5
Jul. 2008-Dec. 2008	35	14087.6
Jan. 2009-Jun. 2006	44	21775.1

Source: collected and calculated according to National Development and Reform Commission

In 2007, Chinese government began to pay those loss direct-combustion power generation projects, within the law limits, a provisional subsidy ￥0.1/kW·h. Table 2 shows that both the number of the loss projects and the total amount of provisional subsidies are on the rapid rise. The numbers of the loss plants have increased from 6 in 2007 to 44 in 2009, a hike of 6 times, both have the total amount of provisional subsidies, nearly 7 times. A conclusion can be easily generalized from the data above that provisional subsidy is one of the most important factors causing the total amount of subsidies to grow rapidly. If no power plants are loss, meaning the provisional subsidies are zero, the total amount will increase at least 1 time less. In addition, it should also be noted that there are up to 44 loss biomass power plants throughout the country by June 2009, while the total number of operating plants is merely 76 with the same period. That is, the losing rate is more than 57 percent, coinciding with relevant reports. This proves that the current situation of China's biomass power generation industry is far from optimistic.

It can be seen from the data above that China's biomass power generation industry is facing

[1] This figure is estimated by monthly means because data from NDRC are divided into periods.
[2] This figure is estimated by monthly means because data from NDRC are divided into periods.
[3] Figures in 2009 are calculated only from Jan. 2009 to Jun. 2009

serious problems, in spite of its rapid development in recent years. After the inaction of the subsidy policy, the subsidy size is quickly enlarged and the total amount doubles, forming a huge demand for fund. Unfortunately, those biomass power plants which have received subsidies do worse, and the number of the lose companies doubles as well, growing even faster than the biomass installed capacity. The shortcomings of subsidy policy seem to appear gradually. But after depth analysis, some different conclusions can be generalized:

(1) The total amount of subsidies won't rapidly increase endlessly.

In the first place, according to specific terms in ***Provisional Measures of renewable energy power generation price and cost allocation management***, every biomass power project enjoys subsidy price for only 15 years, and since 2010, every year's subsidy amount will decrease by 2% over the previous year. Therefore, although the number of power plants continues to increase, the future amount of subsidies will tend to decrease step by step. Furthermore, with more and more plants meeting its subsidy deadline, the subsidy size will gradually become stable in the future. Secondly, according to current reports, the recent rapid development of biomass power generation can be partly due to irrationality of industry development plan and blindly investments of local government. With the administration of renewable energy market more and more standardized, the phenomenon that biomass power generation grows irrationally rapidly in the short term will decrease, and the growth of subsidy amount will tend to be appropriate.

(2) It is not subsidy policy itself that causing great loss of biomass power plants in a large scale.

The design of subsidy policy has deliberately evaded possible adverse influences, like 15 years' subsidy deadline and annually 2 percent decrease, which are mentioned above. These regulations not only financially support biomass power plants in the short term, but also offer incentives for companies to improve their operation and enhance the productivity for a long time. By foreseeing the subsidy amount and deadline, biomass power plants have to continually improve production techniques and intensify their market competition, in order to survive in the power generation marketplace 15 years later. Therefore, it can be assumed that subsidy policy is not the leading cause that making biomass power plants deaden and even get loss. In fact, most biomass power plants' loss due not to their bad operation or management, but objective market conditions, such as an explosion of raw materials cost, irrational gathering and congestion of biomass power plants caused by blindly local investments, etc., which cannot be anticipated when the policy is designed. So, it is not sufficient to ascribe the deficit situations to the maladies of subsidy policy.

In a word, because of coexistence of rapid development and serious deficit situations, we cannot completely deny the effect of subsidy policy, nor confirm its positive benefits. Under the circumstance that state's supports to biomass power generation industry are limited, the phenomenon, that biomass power plants grow rapidly, may well be the result of investors, who focus on pursuit of the maximum profits, earning subsidy profits during the early days of biomass power generation development, rather than the consequence of real market driving. And the bottle-neck period that biomass power generation industry now confronts just offers an opportunity to verify the subsidy policy's efficiency. After realizing the current adverse situation, will more investors continue to invest in biomass power generation market, making the industry keep the increase or even faster over the next one or two years? That is to be proven by further verification.

4.4 General evaluation

4.4.1 Biomass power generation subsidy policy has conceptive and operational specialty

The subsidy is paid by grid power companies, the funds of which come from levying renewable energy additional fees, so it is not a kind of state fiscal subsidy, but a subsidy-like economic power price policy. The operational specialty of the policy not only causes the roles inversion between government and enterprises, but also brings price rising, with the growth of enterprises' tax burden, and the risk of inflation.

4.4.2 Biomass power generation subsidy policy has sustainability

The policy will not bring financial burdens to the government, and it also makes sure keeping a rational subsidy size in the long term, by stipulating the deadline and a decrease of subsidy amount. Besides, to some degree, it also avoids the negative effect from biomass power plants depending too much on the policy and lacking the incentives to improve their operation and management. Generally, this policy makes best use of the advantages and bypasses the disadvantages. Without exceeding consumers' burden limit, it will be a sustainable subsidy policy.

4.4.3 The stimulative effects of biomass power generation subsidy policy have to be proven by further verification

In early period of the development of the biomass power generation industry, the subsidy policy plays an important role in reliving biomass power plants' high cost and improving their competition ability, which can be seen from the growth of total installed capacity. However, it is an indisputable fact that the total amount of subsidies is also prodigious, and the policy does not distinctively promote the techniques or improve productivity. So the stimulative effects of the policy are open to doubt and need to be proven by further verification in the future.

4.4.4 The current price level in China is insufficient

Now the Chinese government still uses the price standard set in 2005. With the growth of raw materials cost, the current subsidy level cannot counteract the highly cost of power generation of biomass power plants. Consequently, over half of biomass power plants get loss, and the whole industry is facing a bottle-neck. A losing rate of 60 percent and rapid growth of provisional subsidies are evidences that current subsidy level is insufficient.

5 Policy suggestions

In order to improve the current situation of biomass power generation industry, multiple measures should be taken to reach the goal. Based on the above analysis, this article proposed several improving suggestions from policy point of view, with a desire to realize better and faster development of biomass power generation industry.

5.1 Short-term policy suggestions

On a short view, the urgent task on hand is to change the adverse situation of biomass power plants. The following is the proposed suggestions.

5.1.1 Raising the subsidy level properly

The subsidy standard set in 2006 cannot adapt to the needs of current market. By June 2009, over 60 percent of biomass power plants can get a provisional subsidy of ￥0.1/kW·h, meaning in fact, the subsidy price have already mounted to ￥0.35/kW·h (0.25+0.1) in most of the country. Since it has been proved that this subsidy policy is a sustainable policy, as a sovereign policy support in biomass power generation industry, the government should raise the subsidy level properly, after fully researches and discussions. For example, make the price at ￥0.35/kW·h directly, or regulate that the benchmark price is based on the latest year, to adapt to the changing market condition and to relieve the deficit situation of biomass power generation industry.

5.1.2 Bringing biomass power generation into the supporting fields of special funds for renewable energy development

Although biomass power generation subsidy does not depend on state finance and won't cause financial stress, renewable energy additional fees imposed on vast electric consumers are rising gradually[1], because of the severe deficit situation of biomass power plants in recent years. Over time, this will inevitably increase the burden on local enterprises, especially in those underdeveloped regions, and even greatly influence local economic. So that is not a permanent solution, and the situation of the single source of the subsidy funds should be changed. We propose to bring biomass power generation into the supporting fields of special funds for renewable energy development. Every year, the government sets aside part of special funds, which is exclusively used for biomass power generation subsidy

5.1.3 Perfecting relevant financial and tax policies as soon as possible

Except for subsidy policy, other financial and tax policies for biomass power generation are relatively scattered and limited, or too narrow size, or insufficient. We propose to perfect relevant financial and tax policies as soon as possible, based on ***Renewable Energy Law***. For example, bring all the production modes of biomass power generation into the range of comprehensive resource utilization to make biomass power plants receive relevant policies support, such as value added tax refunding upon collection, 90 percent income tax preference, etc. In addition, the government should also put forward loans preference policies, to biomass power generation industry, to strengthen the market guiding and impelling forces.

5.2 Long-term policy suggestions

On a long view, the longer term objective is to ensure the sound, steady, and sustainable development of China's biomass power generation industry. The following is the proposed suggestions.

5.2.1 Adjusting the power price or the subsidy level timely to adapt to the changing market condition

According to Article 19 of ***Renewable Energy Law***, the government should adjust the on-grid price of renewable energy projects, as appropriate, in accordance with the principle of promoting the development and utilization of the renewable energy and the basis of economy and rationality. However, now the government keeps using an invariable power price and a subsidy standard for

[1] Level of renewable energy additional fee is ￥0.1/kW·h from Jun. 2006, then adjusted to ￥0.2/kW·h in Jul. 2008, and ￥0.4/kW·h in Nov. 2009.

many years, making an unfavorable development condition of the biomass power generation industry, which not only fails to fit in with the original intention of relevant regulations, but also lacks of conformity with the spirit—adjusting price level—of ***Renewable Energy Law***. So we propose that the government should follow the market conditions and adjust biomass power price and the subsidy level, appropriately with certain cycle, for instance, every year or every two years, thus ensuring a steady development of biomass power generation industry at any market environments.

5.2.2 Finally cancelling the subsidy policy at a specific development stage

Essentially, subsidy policy distorts the real value of biomass power generation and conceals the price parities between biomass and other power generations, which is a kind of market mechanism distortion. The reason that the government offers subsidies to biomass power generation, is because its cost is much higher than common thermal power generation, and is because the government does not levy resource tax, carbon tax on thermal generation yet, making its total cost, without calculating the environmental cost, is relatively on the low side. The subsidy policy truly supports the biomass industry on a short view, but in the long run, price returning value is the inexorable trend. We suggest that the government finally cancel the subsidy policy at a specific development stage, to make biomass power generation fully marketized. The certain stage, is not necessarily when the biomass power techniques have progressed enough to compete with thermal power generation. The government can create the conditions by itself, for instance, taxing thermal generation to make its total cost equal with biomass generation, of course, premise is the national economy can already bear higher power price. In a sum, only in the market mechanism can the biomass power generation industry remain dynamic permanently and develop sustainably.

References:

① Wang Zhongying, Ren Dongming, Gao Hu. *China's Renewable Energy Industry Development Report 2008*, Chemical Industry Press, 2009.

② Gao Hu, Wang Zhongying, Ren Dongming. *Knowledge Reader about Science, Technology and Industrial Development of Renewable Energy,* Chemical Industry Press, 2009.

③ Ren Dongming, Wang Zhongying, Gao Hu. *Knowledge Reader about policies and rules of Renewable Energy*, Chemical Industry Press, 2009.

④ Shi Jingli. *Study on renewable power pricing mechanisms and price policies in China,* Electric Power, 2008(04).

⑤ Li Yanfang, Yue Xiaohua. *Analysis on China's Biomass Power Generation Industry: the Current Situation,Problem and Its Legislation and Policy Recommendations*. Journal of China University of Geosciences (Social Sciences Edition), 2009(3).

⑥ Luo Jun. *Prospect Analysis of Biomass Electricity Generation Technology in China*. Jiangsu Electrical Engineering, 2006(9).

Fiscal mechanisms to promote the development of biomass power generation industry

Yingdan Mei, Li Gao, Zhong Ma, Lei Shi
(School of Environment and Natural Resources, Renmin University of China, Beijing 100872, China.
E-mail: may19880106@163.com)

Abstract:

The paper discusses environmental damage of thermal power and environmental and social effect of biomass power generation, pointing out that biomass power generation plays an important role in our country's energy structure adjustment and the reasons to choose economic policies. Based on this, the paper describes the current situation of the biomass power generation industry, indicating that at present our country's biomass power generation industry stays in the preliminary and weak stage, and needs policies to support it. But policies implemented currently don't work well, so the paper puts forward the idea that using tax and subsidization methods to stimulate the development of the biomass power generation industry. The paper utilizes "renewable resource substitution theory" put forward by Tom Tietenberg to demonstrate that the effect of implementing both tax method and subsidization method is better than only implementing tax method or only implementing subsidization method. Moreover, tax revenue can be used to support subsidy in order to promise persistence and steadiness of the subsidy policy. At last, the paper illustrates some deficiencies.

Key words:

Subsidy, Renewable Resource Substitution Theory, Energy Cost, Biomass generation, Taxes

1. Introduction

As is known to all that SO_2, NOx and other gases, which are discharged by thermal power generation, have polluted our living environment seriously. Moreover, coal that is the material of thermal power generation is the exhaustible resource. So it is important and urgent to develop renewable energy.

However, compared to thermal power generation, biomass power generation discharges gases without pollution. Biomass contains low level Sulfur, about 3% which is the 1/4 of that contained in coal[1]. Biomass can also reduce the emission of COx. It is estimated that installed biomass power generating capacity of 12 MW can reduce COx by 17.8 ten thousand tons[2], which can decrease the emission of green house gases. Furthermore, biomass power generation industry can also increase farmers' income, and enhance the living standard of farmers. Biomass power generation industry can also provide large amount of jobs for farmers, which is presented below.

[1] Xu Zhaofeng, *Argument about Biomass Power Generation*, High-Tech Enterprises of China
[2] Luo Jun, *Prospect Analysis of Biomass Electricity Generation Technology in China*, Jiangsu Electrical Engineering, Vol.25, No. 5

Table 1 Social benefit of National Bio-Energy's Eleventh Five-Year Plan[3]

Items	2006	2007	2008	2009	2010	Total
Disposal of farming and forestry remains/10,000t	3	144	309	674	1130	2260
Recycled use of plant ash/10,000t	0.12	5.76	12.36	26.94	45.20	90.38
Farmers income/billion Yuan	0.010	0.504	1.082	2.359	3.955	7.910
CO_2 reduction/10,000t	1.5	100.1	214.8	468.1	785.4	569.9
Create jobs	3,000	10,000	20,000	25,000	45,000	103,000
Power capacity/billion KW·h	0.01	1.03	2.21	4.82	8.08	16.15
Substitution for fossil fuel/10.000t standard coal	0.4	38.5	82.6	180.3	302.2	604

Compared with other renewable resources, biomass resources have no territory limitation which is the key problem of wind power generation, and biomass is unlike solar power which has difficulty in storage. The material of our country's biomass resources is abundant and easy to store, and biomass power generation can turn waste into benefit, making agriculture waste harmless, valuable. So biomass power generation will be the inevitable choice of China and will be one of main directions of energy structure adjustment.

At present, academic world analyzes the problems of biomass development only from the angle of biomass power generation industry. However, the paper not only discusses the problem from the angle of biomass power generation industry, but also takes thermal power generation industry into account. The paper analyzes the effect of developing the biomass power generation industry and inhibiting thermal power generation.

2. Current situation of our country's biomass power generation industry

Biomass power generation mainly consists of direct-combustion power generation, gasification power generation, mixed-combustion power generation, methane power generation, garbage power generation and so on. At present, the main method of our country's biomass power generation is direct-combustion power generation, and other methods have not gained large-scale application.

After *Renewable Energy Law* has been implemented, our country's biomass power generation industry develops fast, and direct-combustion power generation develops fastest. The table 2 is presented below.

[3] Jiang Dalong. *Prospects of Biomass Direct-f iring Power Generation*. Modern Electric Power, Vol124 No15 Oct1 2007.

Table 2 Types and current situation of biomass power generation in China

Types	Development status	Effectiveness
Combustion power generation	The fastest growing type after ***Renewable Energy Law*** has been enforced in 2006.	From December 2006 to June 2008, a total of 18 biomass combustion power generations has been put into operation, and the installed gross capacity is up to 450,000 kW. In addition, another 70 projects are under construction.
Mixed-combustion power generation	Still under testing period because of lack of specific preferential policies in China.	Shiliquan Power Generation in Zaozhuang, Shandong Province and another 7 generations invested by Xiexin Corp., Hong Kong, have joined the testing.
Gasification power generation	Growing slower than combustion generation because of less mature technologies.	Mainly contain Fujian Putian, Hainan Sanya Timber Mill, Hebei Handan Straw Gasification power generation and one with a capacity of 75 million KW built by Heilongjiang Farms Administration.
Garbage power generation	Growing fast with more mature techniques.	Due to the end of 2005, there are a total of 66 garbage generations in China. In 2006, another 20 generations have been built and grid-connected.
Biogas power generation	Growing fast with mature domestic generating sets.	Due to the end of 2005, there are 3,764 large and medium-sized biogas projects, and the installed capacity of farms biogas projects is 6,699 KW, with a power capacity of 8,726,228 KW·h.

Resources: Gao Hu, Wang Zhongying, Ren Dongming. *Knowledge about Renewable Resources' Science and Industry Development*. Chemical Industry Press, 2009

However, biomass power generation industry develops slower than some other power generation industry, such as wind power generation industry. By the end of 2007, installed biomass power generating total capacity increases to 260 ten thousand KW, compared with that of 2005, increasing by 50 ten thousand KW, at the average rate of 11.3% which is much less slowly than the increasing rate of wind power generation industry. In recent years, biomass power generation industry enters the development bottleneck because of high operation cost, deficiency of technology, market demand, policy supporting and so on. According to the current development speed, it is hard to reach the goal of installed biomass power generating total capacity increasing to 550 ten thousand KW which is set in *Renewable energy development long-term planning*.

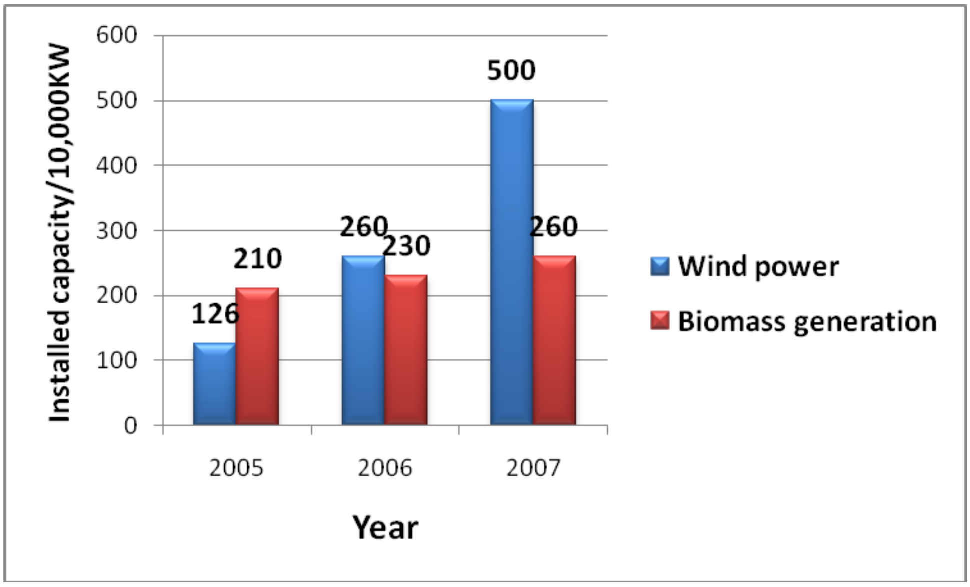


Chart 1 the total capacity of wind power and biomass power generation from 2005-2007[4]

As can be seen from the graph, although the state has been on subsidies to biomass power generation, but its development is still relatively slow. From the analysis above, biomass power generation plays an important role in the energy structure adjustment, but its development is so slow. Therefore the policy needs to be supported. This paper will analyze the effect of subsidies and tax policy to demonstrate biomass power generation's optimal policy routing.

3. Economic policy choice of biomass power generation

Based on the above analysis, the paper proposes the economic policy to promote the development of biomass power generation, which is implementing both tax method and subsidization. The paper utilizes "renewable resource substitution theory" put forward by Tom Tietenberg to demonstrate that the effect of implementing both tax method and subsidization method is better than only implementing tax method or only implementing subsidization method. Because the theory of ***Renewable Resource Substitution Theory*** is based on energy cost, this section firstly analyzes how the subsidies and tax affect the cost of energy.

3.1 Effects of the policy on energy cost

In the long run, resource development is mainly influenced by cost. Whether the resources can be effectively developed mainly depends on the total cost.

The total cost in the paper refers to energy cost[5], other cost (such as collecting and processing cost) in this paper is neglected. The energy cost of the exhaustible resources contains mining cost, use cost, environmental cost. The energy cost of the renewable resources contains mining cost, environmental cost. Use cost refers to the present value of the opportunity cost[6]. because the

[4] Shi Jingli. *Study on Renewable Power Pricing Mechanisms and Price Policies in China*. Electric Power, Vol.41, No.4, Apr.2008.
[5] Tom Tietenberg, *Environmental and Natural Resources Economics(5th Edition)*, Economy and Science Press, 2003.110-160
[6] Zhong Ma, *An Introduction to Environmental and Natural Resources Economics (2ed Edition)*, Advanced

supply of the exhaustible resources is fixed and limited and using a unit of today's resources means using less a unit of tomorrow's resources, deciding to use a certain amount of today's resources means giving up the benefit of future use of the resources. On the contrary, renewable resources have no use cost, and today's use will not result in tomorrow's deficiency, so use cost of renewable resources is zero. Use cost is mainly influenced by discount rate. Environment cost refers to the environmental damage caused by utilizing the resources.

The energy cost of exhaustible resources= mining cost+ use cost+ environmental cost
The energy cost of renewable resources= mining cost + environmental cost

3.1.1 Effects of subsidies on biomass energy cost

Because the biomass is a kind of renewable resources, the energy cost of the biomass consists of mining cost and environmental cost.

Because the biomass is environmentally friendly, its environmental cost is zero and the energy cost of the biomass consists of mining cost. The paper takes straw resources as an example to illustrate the structure of biomass energy cost and relevant influence. mining cost of straw resources is made up of raw material cost, collection cost, bundling cost, storage cost, transportation cost and grinding cost.

The biomass energy cost=mining cost=raw material cost+ bundling cost+ collection cost+ grinding cost+ storage cost+ transportation cost

Different kinds of straw resources have different raw material, bundling cost and collection cost. The corn and cotton have higher cost than others because they mainly rely on labor force and simple mechanical work. Storage cost is mainly influenced by the storage scale and time. Transportation cost depends on the transportation distance and tricycle or four-wheeled tractors are main transportation vehicles. Raw materials are needed to be grinded before transporting to the purchasing centers. Grinding cost includes electricity cost, labor cost and equipment depreciation cost. At present, bundling machine is deficiency and primitive, so work efficiency is too low. The table below shows the cost from farmlands to the plant of a 25 MW biomass direct-combustion power plant.

Table 3 Comprehensive cost of biomass raw materials

Cost structure	**Raw materials**	**Collecting**	**Transportation**	**Smashing**	**Binding**	**Storage**	**Total**
Cost(Yuan/t)	50	75-145	60	10	50-80	25	270-370
Percentage(%)	18.5-13.5	53.7-20.7	22.2-16.2	3.7-2.7	29.6-13.5	9.3-7.1	100

Resources: Gao Hu, Wang Zhongying, Ren Dongming. *Knowledge about Renewable Resources' Science and Industry Development.* Chemical Industry Press, 2009.283

If the state subsidizes the biomass power generation, the mining cost will be lowered, thus lowering the energy cost and marginal energy cost. Subsidies can help producers reduce their expense, thus reducing the total cost, so the energy cost can be lowered.

Educational Press,2006.109

3.1.2 Effects of taxes on energy cost of the coal

Coal belongs to the exhaustible resources and its energy cost consists of mining cost, use cost and environmental cost. Mining cost of the coal refers to various expenses of coal mine enterprise producing coal[7]. Mining cost includes designing cost, producing cost and supporting cost. The table below shows the structure of mining cost.

Table 4 Cost structure of coal mining

Cost structure	Cost link	Percentage of total cost
Designing	Designing	5%
	Craftsmanship	3%
Producing	Arrangement	3%
	Operation	81%
Support	Functional management	5%
	Logistics service	3%

Resources: Zhang Ge，Tan Zhanglu. *Cost Control Analysis and Design For Cost of Coal Production Based on Theory of Value Chain*, Study on Coal Economics, 2006,293.

Use cost refers to the present value of the opportunity cost. Using a unit of today's coal means using less a unit of tomorrow's coal, and deciding to use a certain amount of today's coal means giving up the net benefit of future use of the coal.

Environmental cost also called external cost, means that mining and utilization of coal resources causes degradation of other nature elements.

The production and burning of coal can cause the destruction of other ecological environment resources, such as the destruction of coal associated resources (copper, iron, sulfur and so on), water resources, land resources; mining the coal can result in the ground subsidence, farmland disappearance, loss of agriculture production; The process of mining can also generate large amount of solid waste, such as waste rock which not only occupies large scale land, but also ignites automatically under certain circumstances, and emits SO2, NOx, COx, dust and other harmful gases, which does harm to the citizens' health; waste water from mining and washing discharged to the surrounding area generates environment pollution[8]. All of these are the environmental cost related to the coal resources.

Xu Xiangyang puts forward in *The Theory and Application of pricing and Shadow Price of Coal Resources Marginal Opportunity Cost*[9] that the energy cost of the coal resources consists of direct production cost, external cost and use cost, and estimates that the marginal energy cost is about 231.77 yuan/t, less than the biomass energy cost.

Therefore, supposing that technical level remains the same, if imposing taxes on pollutant discharged by thermal power generation, the capacity of thermal power generation will be reduced

[7] Fu Li, Wang Xuefeng, *Coal Mining Enterprises Cost Accounting and Reform Countermeasure*, China Coal, Vol.36, No.1 Jan.2010

[8] Meng Si, Yu Rongrong, *Research on Coal Enterprises' Environmental Cost Structure*. China Management Informationization, Vol.12 No.23, Dec 2009

[9] Xu Xiangyang, *The Theory and Application of pricing and Shadow Price of Coal Resources Marginal Opportunity Cost*, Study on Coal Economics, No.8 1998

and then the demand of coal resources will be decreased, thus the price of the coal and profits will be lowered. It also means that the mining cost is increased. So imposing taxes on thermal power generation is equal to increasing the energy cost of coal resources.

3.2 Choices of different policies

Supposing that:

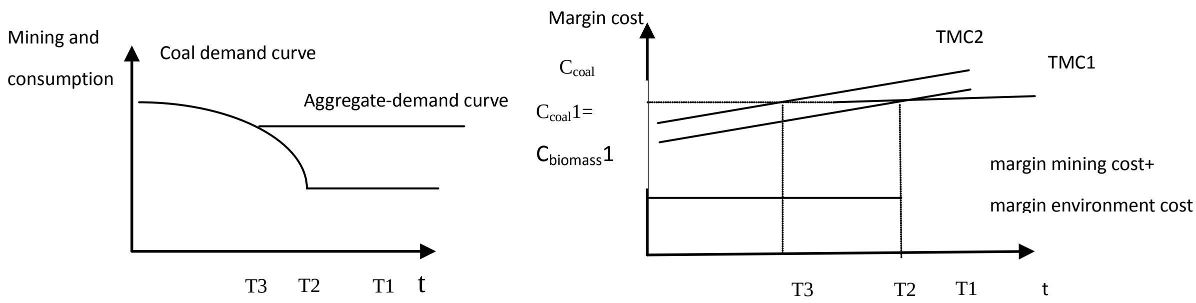
(1) Substitution time can illustrate the effects of different policies;

(2) Before coal is exhausted, there exists a moment at which the biomass energy cost is equal to the coal energy cost;

(3) The supply of biomass raw materials is sufficient.

3.2.1 Neither imposing taxes on thermal power generation nor subsidizing on biomass power generation

When no policy is implemented, that is neither imposing taxes on thermal power generation nor subsidizing on biomass power generation, biomass power generation industry develops slowly. There are only some sporadic, small scale, and spontaneous biogas power plants. At this time, the cost of biomass power generation is too high. Supposing that biomass energy cost, $C_{biomass}1$ less than C_{coal} and that technical level remains the same.



（a1）　　　　（b1）

Figure 1 Substitution bio-energy for coal-energy 1

Figure(a1) shows that in conditions of neither imposing taxes on thermal power generation nor subsidizing on biomass power generation, when the potential consumption and mining reduce to the extent in which the energy cost of coal resources is equal to biomass energy cost, biomass energy will substitute coal resources. Figure (b1) shows the change of total marginal cost, marginal use cost, marginal environment cost and marginal mining cost of resources. At T2 biomass resources substitute coal resources, at this time $C_{coal}1= C_{biomass}1$. the renewable resources replace the exhaustible resources. C_{coal} means total marginal cost of coal resources when exhausted without substitution resources.

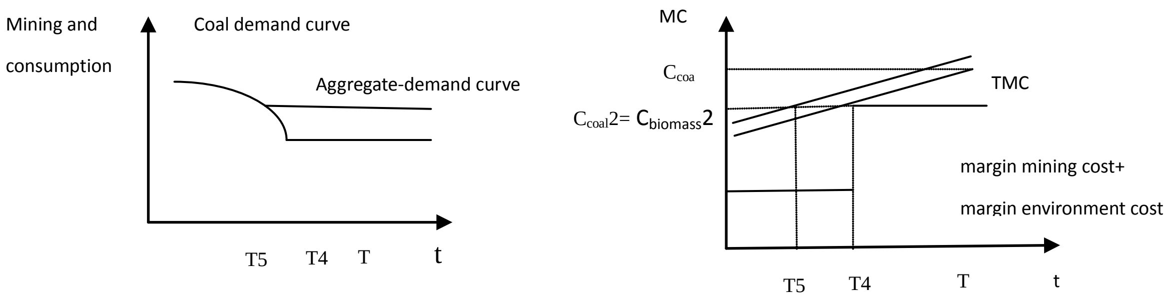
3.2.2 Imposing taxes on thermal power generation but no subsidizing on biomass

power generation

Because there is no subsidizing on biomass power generation, marginal energy cost of the biomass resources remains the same and is still $C_{biomass}1$.There is no positive effect on the development of biomass power generation industry. However, imposing taxes on thermal power generation makes marginal energy cost of coal resources increase. The chart above shows that curve MC1 moves to curve MC2. When biomass energy substitutes coal energy depends on the time when marginal energy cost of biomass resources equals to marginal energy cost of coal resources, that is $C_{coal}1= C_{biomass}1$ at T3 (T3<T2<T1). It can be seen from this that imposing taxes on thermal power generation but no subsidizing on biomass power generation can help earlier realize biomass resources replacing the coal resources, thus lowering the damage to the environment caused by coal resources.

3.2.3 Not imposing taxes on thermal power generation but subsidizing on biomass power generation

Subsidizing on biomass power generation can reduce marginal mining cost of biomass resources. Supposing that subsidizing on biomass power generation reduces the marginal mining cost of biomass resources to $C_{biomass}2$. And when marginal energy cost of biomass resources equals the energy cost of coal resources, biomass resources will substitute coal resources at the point of $C_{coal}2= C_{biomass}2$, which is showed in the Figure2 below.



（a2）　　（b2）

Figure 2　Substitution bio-energy for coal-energy

From the chart we can see that when $C_{coal}2= C_{biomass}2$, biomass resources will substitute coal resources at T4 (T4<T3<T2<T1). Therefore, subsidizing on biomass power generation can reduce marginal energy cost of biomass resources, stimulate the development of biomass power generation industry, and earlier realize that biomass resources substitute coal resources, thus decreasing the damage to the environment.

3.2.4 Both imposing taxes on thermal power generation and subsidizing on biomass power generation

When the state both imposes taxes on thermal power generation and subsides on biomass power generation, marginal energy cost of biomass resources will be lowered and at the same time marginal energy cost of coal resources will be increased. Supposing that subsidizing on biomass power generation reduces the marginal mining cost of biomass resources to $C_{biomass}2$. And imposing taxes on thermal power generation makes the curve of total marginal energy cost of coal resources move up (chart below). When marginal energy cost of biomass resources equals the energy cost of coal resources, biomass resources will substitute coal resources at the point of $C_{coal}2= C_{biomass}2$ at T5 (T5<T4<T3<T2<T1). Therefore, when the state both imposes taxes on thermal power generation and subsides on biomass power generation, it can promote the development of biomass power generation industry and at the same time restrain the development of thermal power generation industry. Thus biomass resources can substitute coal resources much earlier, reducing the environmental damage to the greatest degree.

4. Conclusions

From what has been analyzed above, we can draw the conclusion that:

(1) When there is no policy implemented, that is neither imposing taxes on thermal power generation nor subsidizing on biomass power generation, the development of biomass power generation industry will be too slow and it will take a long time to substitute coal resources.

(2) when only imposing taxes on thermal power generation or only subsidizing on biomass power generation, it can realize that biomass resources substitute coal resources earlier. Only subsidizing on biomass power generation can reduce the energy cost of biomass resources, thus promoting the development of biomass power generation industry. Only imposing taxes on thermal power generation can increase the energy cost of coal resources and make biomass resources substitute coal resources earlier.

(3) When both imposing taxes on thermal power generation and subsidizing on biomass power generation, the substitution time is shortened. Because it not only increases the energy cost of coal resources but also reduce the energy cost of biomass resources, biomass resources substitute coal resources much earlier and much better. Therefore, the most efficient policy route is both imposing taxes on thermal power generation and subsidizing on biomass power generation.

(4) Shen Manhong puts forward in *Study on Methods of Environment Economics*[10] that the environmental subsidy and tax can both make the whole society's net benefits increase and improve the social welfare. In many cases, the obvious flaw of subsidy is that persistence of the subsidy cannot be guaranteed. Fiscal expenditure always cannot promise the continuity of the environmental subsidy and this is the main reason that the environmental subsidy always loses effectiveness. however, the paper puts forward that environmental taxes gained from thermal power generation industry can be used as special fund for the subsidy of biomass power generation industry. Thus the continuity and effectiveness can be guaranteed. in order to make sure that tax revenues are regarded as the source of biomass subsidy funds, there must be a set of elaborately established budgets and sound internal control system of special fund utilization and establishing effective audit institutions which can track the implementation of budgets and play an important in internal supervision.

The limitations of the paper

(1) The demonstration above is based on the constant technical level. In fact, it can happen that when imposing taxes on thermal power generation, thermal power plants are likely to innovate their technology which can emit no or less contaminated gases. Under this circumstance,

[10] Shen Manhong, *Study on Methods of Environment Economics,* China Environmental Science Press, Nov. 2001, 110-130

imposing taxes on thermal power generation industry cannot increase the energy cost of coal resources.

(2) The paper is also on the basis of abundant raw material supply of biomass resources. However, the paper does not prove that our country's biomass resources can satisfy the need of substituting the coal resources without slowing down the economic development.

References:

Xu Zhaofeng, Argument about Biomass Power Generation, High-Tech Enterprises of China

Luo Jun, Prospect Analysis of Biomass Electricity Generation Technology in China, Jiangsu Electrical Engineering, Vol.25, No. 5

Jiang Dalong, Prospects of Biomass Direct-firing Power Generation, Modern Electric Power, Vol124 No15 Oct1 2007

Shi Jingli. Study on Renewable Power Pricing Mechanisms and Price Policies in China. Electric Power, Vol.41, No.4, Apr.2008.

Tom Tietenberg, Environmental and Natural Resources Economics (5th Edition), Economy and Science Press, 2003.110-160

Zhong Ma, An Introduction to Environmental and Natural Resources Economics (2ed Edition), Advanced Educational Press,2006.109

Fu Li, Wang Xuefeng, Coal Mining Enterprises Cost Accounting and Reform Countermeasure, China Coal, Vol.36, No.1 Jan.2010

Meng Si, Yu Rongrong, Research on Coal Enterprises' Environmental Cost Structure. China Management Informationization, Vol.12 No.23, Dec 2009

Xu Xiangyang, The Theory and Application of pricing and Shadow Price of Coal Resources Marginal Opportunity Cost, Study on Coal Economics, No.8 1998

Shen Manhong, Study on Methods of Environment Economics, China Environmental Science Press, Nov. 2001, 110-130

A Political Economy of 'Small Coal Mines Phenomena' in Shanxi Province: Towards A 'Endogenous Development Model'

by Yun Chen
yunchen@fudan.edu.cn
Associate Professor,
School of International Relations and Public Affairs,
Fudan University, China

Introduction

During the process of Chinese gradual way of reform, the progress in systemic transition of respective region in china has been varied. The aim of this paper is to investigate problems of its development and possibility of breaking away from those problems with paying attention upon Shanxi Province which is located in Chinese Central Region and is rich in natural resources.

China has been the largest coal production country in the world which has occupied 37 percent of the world production. Also coal has been the most important energy resource in China, the share of which as regards production and consumption of the primary energy in China occupy 76 percent and 69 percent respectively[1]. In China, particularly, Shanxi province has been well known as the most important coal production base.

'Small coal mine' was defined as a coal mine which had 'less than nine tons' production annually, and most of which had been managed by private owned enterprises. However, since 2008, through the new regulation policy on coal employed by Shanxi province government, the criterion about the annual production of 'small coal mine' has been changed to have less than 30 tons production annually.

Phenomena related with 'small coal mines' are such various ones as outbreak of accidents, environmental pollution, waste of resources, and corruption of government officials. It means, therefore, that 'small coal mines phenomena' can be said as a giant scale living organizational system, in which such various problems as political, economic, environmental, cultural have coexisted closely and complicatedly.

The 'small coal mines phenomena' are not peculiar to Shanxi province, but coal mine regions (chiefly indicating eight provinces in China) have shared such phenomena as mentioned above. Because, however, Shanxi province has occupied top positions in coal deposits and coal mining, the 'small coal mines phenomena' in Shanxi province have become remarkable proportionally.

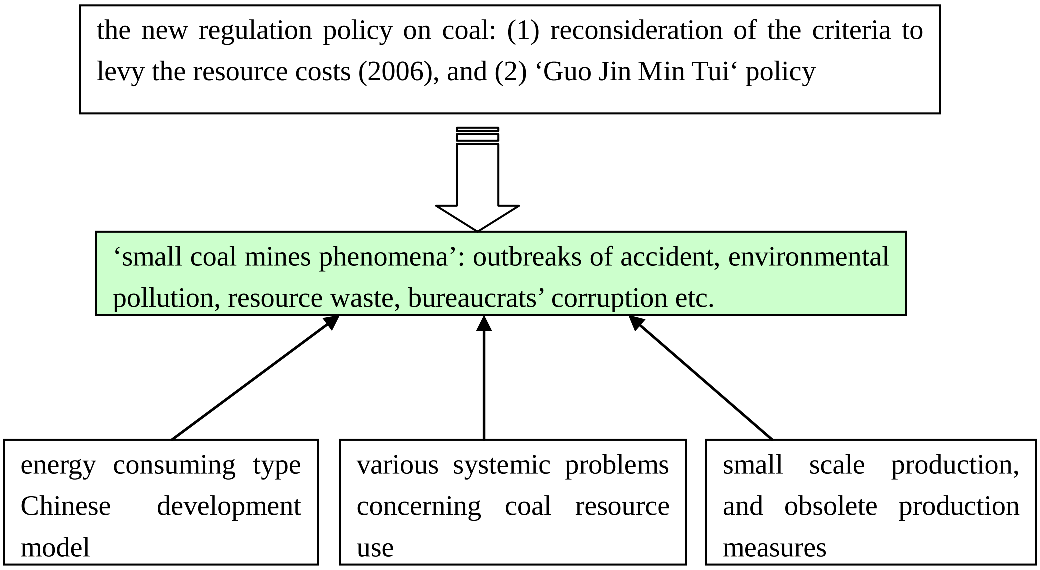
The purpose of this paper is to examine the questions asking why 'small coal mines phenomena' have occurred, what 'small coal mines phenomena' have suggested. By investigating the above questions, by utilizing the research method of 'political behaviorism' and by observing the behaviors of various players appearing on stage entitled 'small coal mines phenomena', the author has above all tried to consider the course of systemic transition in China.

Figure 1 shows the reasons of occurrence of 'small coal mines phenomena' and the contents of the new regulation policy on coal led by Shanxi province government. Shanxi province government has emphasized the 'small-scale production' and 'outdated way of production' as the reasons of occurrence of 'small coal mines phenomena'. However, in this paper, author would like to pay more attention upon other two systemic reasons; (1), as the external aspect, 'energy consuming development model in China' and (2), as the internal aspect, 'various systemic problems on coal resource utilization', which have involved complicatedly. Thus, the 'small coal mines phenomena' coming from the 'small-scale production' and 'outdated way of production could be interpreted as the results of the above internal aspect.

The new regulation on coal led by Shanxi province government has been implemented with two stages, whose first was introduced as the 'reexamination of criteria on resource cost collection' in 2006, and whose second was introduced as the 'Guo Jin Min Tui' policy (meaning that big scale state owned coal mining enterprises merged and acquired small scale private owned coal mines compulsorily) –this term was not used by Shanxi province government, but used by outside commentators, and Shanxi province government has denied it- in 2008.

Based upon the above, this paper is composed of the following sections. In the first section, the author analyzes the tasks to clarify the 'multi-paths' in Shanxi province and to construct the 'endogenous development model'. In the second section, current situations of the 'small coal mines phenomena' in Shanxi province as a giant scale living organizational system and the deeper-rooted systemic factors are investigated. In the third section, in order to eliminate the 'small coal mines phenomena', problems on the new regulation policy on coal in Shanxi province, which are wavered between government and market, are pointed out. In the fourth and the final section, the author looks back upon the roots of Shanxi at the days of 'Jin Shang' (Shanxi merchants) and investigates the possibility on the 'endogenous development model'.

Figure 1. Reasons of 'small coal mines phenomena' and the 'new regulation policy on coal' led by Shanxi province government



Source: Author

1. 'Multi-paths' in Shanxi province and the tasks to construct the 'endogenous development model'

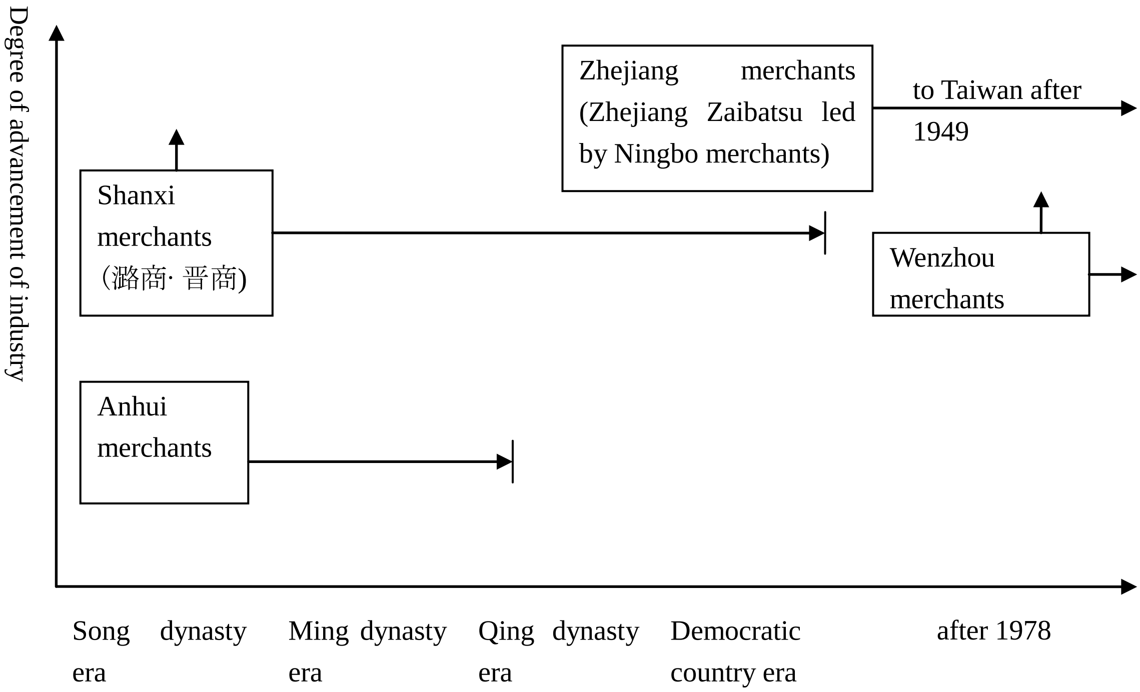
In the regional studies, the sustainable development is the most important and the most fundamental task to be investigated. As regards the economic development in Shanxi province, are such series current problems upon development, which have been, for example, industrial structure problem depending upon coal, the 'small coal mines phenomena' and the decline problem to be a 'resource exhausted city', inevitable results? When the history of 'Jin Shang' (Shanxi merchants) is looked back upon, it is clear that they might not be inevitable.

Establishing the current situation of depending upon coal in Shanxi has mainly been coming from Chinese development strategy after the new China was found. That is to say, the 'path' embedded in Shanxi province was seemed to be compulsory changed. Thus, in investigating the sustainable development in Shanxi province, we have to consider the historical legacy named 'multi-paths'.

With the concept of 'path dependence' insisted by the new institutional economics, we can interpret the development phenomena in developing countries, some of which cannot be satisfactorily understood by the neoclassical economics. Thus the new institutional economics has been focused more attention. However, the author thinks in this paper that the paths have been various because of different behaviors by respective individuals, and there could be existed the analytical framework entitled for example the 'multi-paths'. Then the author thinks that we should classify various paths from viewpoints of development strategies and verify the useful and useless facts, of which we appropriately incorporate in sustainable development strategies to embed them in more institutional framework. In this paper, the author calls the incorporated development model in development strategies the 'endogenous development model' and the independent development model from development strategies the 'exogenous development model'. In that sense, the author could not help saying that the economic development model in Shanxi province which has been suffered from the 'small coal mines phenomena' and the 'Guo Jin Min Tui' is still at the stage of 'exogenous development model'.

When we consider the paths of Shanxi province, at least the following three could be recognized.

Figure 2. 'Multi-paths' and 'Endogenous Development Model'



Source: Author

1-(1). The roots of historically existed Lushang(潞商) and Jin Shang(晋商)

As the first path, we can date back to the days of historically existed Lushang(潞商) and 'Jin Shang'. The Lushang(潞商) can be recognized as the forerunner of the 'Jin Shang'. The former was well known as the processor and the seller of coal mines and coal products, and the latter was famous for the originator of Chinese finance business.

We will follow the history of Lushang(潞商) and Jin Shang(晋商)(see Table 1).

As mentioned above, the process from Lushang(潞商) to 'Jin Shang' can be traced. The Lushang(潞商) as the forerunner of the 'Jin Shang' developed handicrafts and side business based upon the steel industry in 蔭城. Also the construction of industrial chain from resource mining to distribution seemed to be characteristics of the「潞商」model.

To the contrary, the 'Jin Shang', who developed finance business all over China and all over the world by utilizing the close human network with the Qing dynasty, founded the early days banking business named Piaohao(票号) and directed the magnificent behaviors.

Table1. Historical path in Shanxi province: on the days of Lushang(潞商)and Jinshang(晋商)

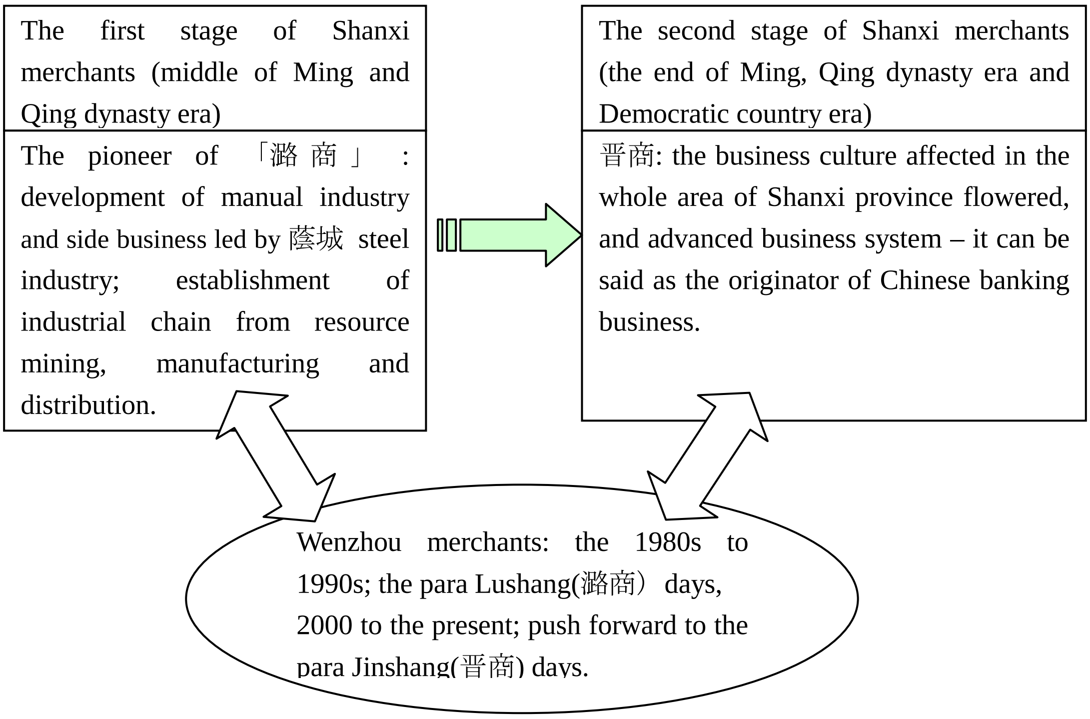
	era	site	characteristics
Lushang(潞商)	era between Wanli (万暦)at the middle of Ming dynasty and Daoguang(道光) of the Qing dynasty	Shangdang(上党) area (Changzhi(長治) at present)	establishment of industrial chain from resource mining, manufacturing and distribution. Moreover, development of the ore manufacturing and distribution contributed for the side business of agriculture. The miracle of Yincheng(蔭城) (which is a small basin) was coming from the strong business mind and the personal attractiveness of the merchants. The characteristics of Lushang(潞商) are the whole family business, subdivided division of labor, distribution network in whole country, and sincere management, which are the reasons of accumulated wealth of Lushang(潞商).
Jinshang(晋商)	Jinshang in a broad sense includes 潞商, but 晋商 in a narrow sense indicates the merchants, who had successful management of 票号 in Qing dynasty era.	whole area including Pingyao county(平遥県) and Qixian County(祁県)	since the Qing dynasty era, the business culture affected in the whole area of Shanxi province flowered. Particularly, advanced business system- Piaohao(票号) (initial stage of banking business) – started from this area. Jinshang(晋商), who succeeded in Piaohao(票号) business, can be said as the originator of Chinese banking business.

Source: Author

As a matter of fact, a group called as the 'Wenzhou merchants' tried to unit the「潞商」and the 'Jin Shang' (see Figure 3). The 'Wenzhou model' until the 1990s was said as the 'small number of goods and large scale of market' and was similar with 潞商 model. (However, in Zhejiang province which includes Wenzhou city, they have scarce natural resources and seek necessary resources for processing from recycled resources. In order to secure the recycled resources, in the whole area of Zhejiang province, venous industry has been developed. Moreover, collecting the resource waste has become developed and the chain of arterial industry and venous industry (which indicates from import – classifying and dismantling – market transaction – local industry)[2].

Meanwhile, since the beginning of 21st century, enterprise groups, which have developed in Wenzhou city, have started actively the ‘Wenzhou foundation’. Development the manufacturing needs inevitably advanced financial service. Both Piaohao(票号) in the old days and ‘Wenzhou foundation’ at the present time occurred spontaneously, which came from reasonable market mechanism.

Figure 3. Similarity between Shanxi merchants and Wenzhou merchants



Source: Author

Even in the ancient peasant economy days, even in the days of planning economy during 1949-1978, even if strict regulations against the private-owned commodity economy were imposed, the grass roots behaviors by merchant groups in respective regions in vast China have been very active (as shown in Figure 2). Even though there are the days of being in hiding, finally such activities come into bud and develop. In that sense, reform and open door policy started in 1978 might not begin with a single authoritative word from a top political leader, but might begin with private-owned power which had strong sympathy with the leader’s strategy.

1-(2). Legacy of the days of centrally planning economy

As the second path, we think it is the legacy of the days of centrally planning economy, in which, as the development strategy of the nation, the heavy chemical industry occupied the first priority. Because Shanxi province has been rich in coal deposits, to break with the 'Jin Shang' was necessary. Also such compulsory process for breaking with was in hands of central authoritarian system.

Shanxi province is located in Central region in China, and is classified as a low level province in economic development. On the other side, however, Shanxi province is rich in coal resource, in which they have established the industrial structure depending on primary commodity. Needless to say, we can easily recognize there are lots of primary commodity production countries (although Shanxi province is not an independent country and coal resource existed in that province is not province-owned).

Then what should we think about the contemporary Chinese economic situation which shows that resource rich regions are less developed and resource poor regions are more developed? It might be interpreted with the 'path dependence' (as the 'Dutch disease' has been explained) , but actually it was fact that, in the Qing Dynasty days, 'Jin Shang' (Shanxi merchants) took the lead in 'Qian Zhuang' (early stage of banking business), which suggested what for us? According to the author's way of interpretation, the primary commodity production industry in Shanxi province was not established spontaneously but was established with political purpose (in the centrally planned system). At present, China has been in the transition process towards market oriented system, however, China has never been fully shifted from centrally planned system. It can be thus said that economic development in Shanxi province has been deeply dependent on the degree of transition towards market oriented system. .

1-(3). Serious influence over coal depending Chinese development model at the days of reform and open door policy period

As the third path, various adjustments of the nation's policy implemented at the days of reform and open door policy have made a new path. Particularly, Chinese high speed and coal depending development model has had serious influence over the Shanxi province.

In primary energy use, Chinese ratio of dependence on coal has reached around 70 percent. During the period of Eleventh Five Year Plan (2006-2010), China progressed in development of recyclable energy. However, it might be difficult to expect that the importance of coal energy use will be diminishing significantly. It shows thus that, as coal is the most important energy for economic development, profit oriented competition upon coal might become hotter (particularly in the period of economic expansion). The 'small coal mines phenomena' become symbolic scenes for the keen competition. As contemporary Chinese development model is characterized by 'low cost dependence', 'energy consumption type industries dependence' etc., we should think that, when without evolution of development model, it automatically means without the 'small coal mines phenomena'.

Generally speaking, the low cost dependent development model in China basically depends upon the three low costs; they have never paid much attention to (1) workers' rights and interests, (2) environmental costs, and (3) resource costs. Coal resources focused in this paper have occupied the most important position of all the primary energy uses in China on the one hand. On the other hand, however, in the coal production concerned, in addition to the low level wage rate, both workers' safety and health have paid less attention (because, for workers in the poor regions located in Central and Western region, income level at the coal mines is higher than other jobs, and because workers in Central and Western region have less opportunities to have non-agricultural jobs, most workers wish to work at the coal mines although there are more risky factors). Moreover, negative influence against the environment (water, soil, and other natural environment) in and around the area of coal production has never been added up as costs[3]. It means that, although Chinese coal industry has been the upstream industry contributed for Chinese high speed economic growth, the coal industry itself has been in the low cost dependent structure as the same as Chinese development model.

1-(4). Systemic transition: the process of continued movement of equilibrium

The 'systemic transition' as a large scale project (gradual institutional change) can be said as the process of continued movement of equilibrium. Needless to say, the continued movement of equilibrium might not always go smoothly. Either 'gradual post-path' process or 'compulsory breakthrough' is not easy to be implemented. Either 'unstable movement' or 'retrogression' is possible to do. In particular, in the case of 'shock therapy' (which is the way of 'compulsory breakthrough'), systemic disturbance might be easy to occur.

As a matter of fact, from the days of 'Jin Shang', Shanxi province has experienced various ecdyses. Of those ecdyses in Shanxi province, all of the first ecdysis after the year of 1949, the second ecdysis after 1978, and the third ecdysis after 2006 (which is the so-called 'new regulation policy on coal') were relatively more 'compulsory breakthrough'. In those compulsory policies, the first was led by central government, and the second was by corporation of central government with Shanxi province government, and the third was mainly led by Shanxi province government. When looking back upon those 'compulsory breakthrough' cases, both policies of Youshuikuailiu(有水快流)(indicating that, in the coal resource regions, with employing all the possible measures, they have profits by mining coal) and 'Guo Jin Min Tui' (meaning that big scale state owned coal mining enterprises merged and acquired small scale private owned coal mines compulsorily) have shown that systemic disturbances were not settled.

How can Shanxi province plan a sustainable development strategy?

The author wishes for Shanxi development model to converge to the 'endogenous development model' (as regards the development model, see later section).

2. The 'small coal mines phenomena' in Shanxi province as a big ecological system

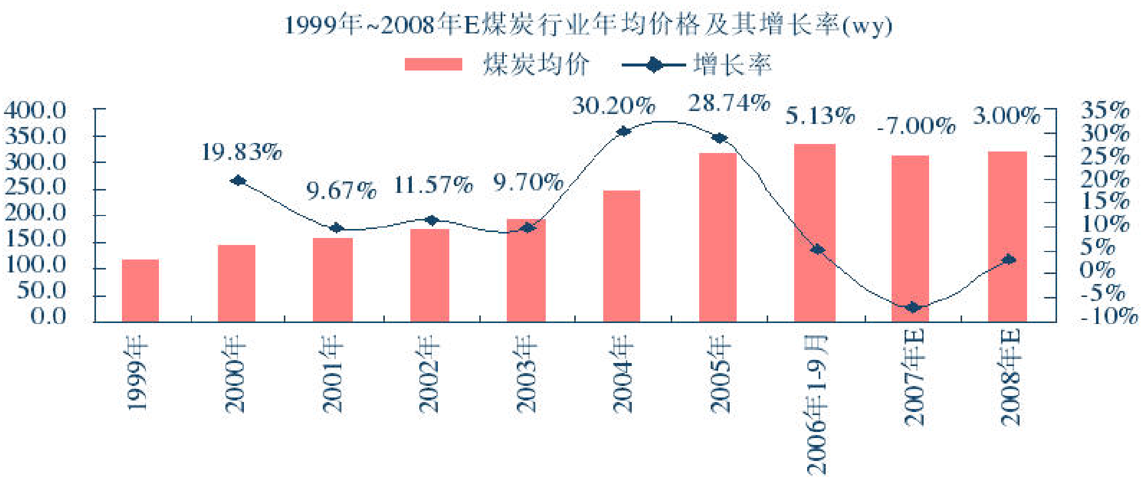
2-(1). Transformation of coal industry in Shanxi province

In the 1990s, when China experienced business fluctuations, management and profit in the coal industry seriously fluctuated. In the end of 1990s particularly, demand in the coal market shrank. Then lots of small coal mines managed by collective enterprises in towns and villages were on the verge of collapse. They were reluctantly sold to private owned enterprises (many number of private enterprises managed by Wenzhou merchants, who are called as 'Jews of the Orient', implemented their new entries in coal mining industry in Shanxi province then).

After the year of 2000, when Chinese economy became active, the 'small coal mines phenomena' appeared various places and the existence of Wenzhou merchants has become more remarkable. At the same time, however, such development of 'small coal mines' was accompanied by outbreak of accidents, environmental pollution, waste of resources, and corruption of government officials as mentioned previously. After the year of 2006, in Shanxi province, the new attempt to reform the property rights (the new regulation policy on coal) has started, in which particularly 'Guo Jin Min Tui' (meaning that big scale state owned coal mining enterprises merged and acquired small scale private owned coal mines compulsorily) policy developed since the year of 2008 and caused serious and hot discussions. Also in order to protect the benefit of Wenzhou investors, Zhejiang province government has begun to negotiate with Shanxi province government (as mentioned previously, many Wenzhou merchants invested lots of money in the small coal mines located in Shanxi province, and, because of the 'Guo Jin Min Tui' policy, they suffered the loss of huge amount of money), however it is difficult to say such negotiations between the two provinces produced any positive effects. (In March, 2010, senior member committee of Chinese Cabinet declared the policy of deregulation and of promotion for new entry into lots of sectors which were fully monopolized until then, to officially respond to the popular discussions among Chinese citizens on the validity of 'Guo Jin Min Tui' policy. See also section three on this issues).

Figure 4 points out the movement of coal price in 1999 – 2008, which shows the price increase year after year.

Figure 4. Movement of coal price (1999 – 2008)



Source: Research Report web site of Junlue(君略), http://www.dataci.cn/Html/Coal/

Generally speaking, since the 1980s, the characteristic structure of Shanxi economy (which is fully depended upon coal) has been moving ahead. Industrial structure of the province has been more concentrated in such coal related four industries as coal, metallurgy, coke, and electricity. In the year of 2005, the amount of industrial value added production of such four industries occupied 80 percent of the total of industrial value added production. Also around the half of budget revenue was occupied by the four industries[4].

It suggests us the 'Dutch disease' would be realized in China. Needless to say, the 'Dutch disease' indicates that natural resource rich region is depended too much upon the resources (resource exports appreciates the exchange rate, which seriously damages the manufacturing sector of the economy concerned). According to such a disease, the economy becomes the resource exhausted and finally sinks. The disease cursed by resources would be carried out in China.

At present, China has altogether 118 resource depended cities, of which coal mine cities occupy more than half. In March, 2008, the first 12 resource exhausted cities were recognized, and then in March, 2009, newly recognized 32 cities were added. We should thus recognize that in China spellbinding by resources have already been realized.

The 'small coal mines phenomena' in Shanxi province (which is investigated here in this paper) indicate the arena of the 'path' and the 'real', and also they have contributed to clarify the relationships between 'government and market', 'central government and local government' and relationships among local governments. In addition to the above, such problems as poverty and human rights of coal mine workers, current situation on corruptions of local government officials, sustainable development of Shanxi province have been brought about.

The author will analyze the problems in later sections.

2-(2). What are the explanations of 'small coal mines phenomena' ?

Remarkable characteristics of coal industry in Shanxi province are, what is called, the 'small coal mines phenomena'. The small coal mines have been recognized as related with environmental destruction, resource waste, frequently occurred accidents, cozy relationships of merchants and bureaucrats. It has been rather often pointed out that those problems are coming from small production size and obsolete technologies. those were reasons with which the new regulation policy on coal was emphasized to be valid. However, the author thinks that, as the reasons occurred as the 'small coal mines phenomena', more important reasons were energy consuming type development model and various systemic problems (as mentioned later) in the coal resource use than the small production and obsolete technologies, the issue to eliminate the 'small coal mines phenomena' is not as simple as of dealt effectively with compulsory mergers and acquisitions. Thus, in order to break away from the 'small coal mines phenomena', the final solution should reach to the Chinese systemic transition.

In this section, the author tries to explain the phenomena concretely and to observe the players appearing on the stage.

(1) On the environmental destruction and resource waste problem.

Small coal mines have only the right to use and also, as the mining rights have with a time limit, the phenomena to mine coal more than estimated quantity of production have been common. Also because the resource costs are calculated based upon actually mined quantity of coal, the ratio of mining (which means, within a certain extent for a mining factory, the ratio of actually mined quantity to the coal deposits) has been very low (whose ratio of small mines in whole China has been said as 20 – 30 percent). The phenomena of resource waste are remarkable. Furthermore, it is not uncommon that small mines have actually mined coal across a boundary which is needless to say illegal. Those behaviors have caused various resource waste and ecological destruction.

In order to increase the ratio of mining, in the year of 2006, reconsideration of criteria to levy resource costs was done. However, it is undoubtedly clear that the effect is not enough (as is mentioned later).

(2) Problem on the outbreak of accidents

In China, each of property rights (the nation) and the rights to use (enterprises as the investors) is totally different (as mentioned later). Needless to say, the mining rights (the rights to use) have a time limit. It is usual that, the investors (who have the mining rights) are self-employed (doing business the coal mine on their own) and introduce a subcontract system. Under the multiple subcontracts system, like the terraced fields, investment expenditure to secure safe production has been cut down on, and any device to minimize the costs has been implemented by subcontractors[5].

Such profit maximizing behaviors as implemented by enterprises have caused the effects of synergy with various inadequate management systems for coal industry, which finally reach outbreak of accidents.

According to the statistics of the year 2006, the coal production of the small mines occupied 37.9 percent of total production in China. However, the ratio of the number of accidental death reached 72.3 percent. Also the number of accidental death per one million tons coal production was counted to be 3.885, which was 6.19 times more than state-owned great important mines and was 2.04 times more than local government managed state-owned mines respectively.

The obsolete technology of small mines (low ratio of mechanized mines and most mines are done by workers) seemed to be serious reason of the accidents, by which 'Guo Jin Min Tui' policy was justified. However, the author thinks that, because such radical reforms as various management systems about the 'small coal mines phenomena' have never been contained, the effects on the above policy have been doubtful (on the effects of this policy, see later in this paper).

(3) Serious current situation upon cozy relationships between merchants and bureaucrats

Since the 1980s, the rights to mine coal of private-owned enterprises have been allocated by administrative authorization, not by market mechanism. Therefore, people have been surprised to know that (a) it has been irrational because state-owned resources have been acquired by private-owned enterprises almost free of charge, and (b) it has been serious that cozy relationships between merchants and bureaucrats have been deep-rooted. In place of 'free of charge', huge amounts of 'social expenses' (bribery) were handed over in the process of acquiring the rights to mine coal, whose cozy relationships would continued (such various ways of coziness as continuous entertainment for local government officials, continuous bribery, transfer the parts of stock certificates of the coal mines to local government officials – usually known as 'officials' stocks' –[6]). By the way, small coal mine owners have done their hard work to keep up their mining rights, which they acquired 'irrationally', by throwing a lot of 'social expenses' around (to various levels government officials and organizations). Thus, lots of local government officials working for government organizations have been parasitic on small coal mine owners. It should be said that it has been a distorted plot coming from a distorted social structure occurred at the days of systemic transition.

During the days of systemic transition in China, not only in the small coal mines but also in lots of other fields, corrupted practices among government officials have been recognized. The prevailing corruptions all over China for which Chinese ordinary citizens have paid have caused the peoples' distrust of politics.

The author thinks that government led development model promoted under the authoritarian system have gradually been caught in a dilemma.

2-(3). Systemic problems over the coal resource use in China

As shown previously, the tangible signs of 'small coal mines phenomena' could reach the deep-rooted reasons coming from various systemic problems such as energy consuming development model and coal resource use. As regards the former case, the author has mentioned in another opportunity[7]. Here in this paper, the latter case would be mainly focused.

2-(3)-(1). Systemic problems on the mining rights of coal resources

First, it should be recognized the problem on administrative authorization about the mining rights.

With the Youshuikuailiu(有水快流) policy (see the previous-mentioned explanation), coal industry has developed and local government has received tax revenues. On the other hand, however, a great variety of problems have been brought about. For example, due to the systemic custom of centrally planning, in the 1980s, the coal mining rights could be acquired with free of charge by the administrative authorization. The problems coming from the above are; (A) even the rights to manage coal mines have been handed over to private-owned by such a system as contract system, non-state-owned coal mines have kept on receiving the free acquisition of resources. Also as regards the state-owned coal mines, the allotment of the nation (the rights of receiving revenues) has never been secured[8]. In addition to the (A), (B) the huge disparity between the profit gained from the market (at the economic expansion period) and the freely acquired mining rights has become a hotbed of corruptions (as mentioned previously).

Second, it should also be recognized the separation problem of property rights from mining rights.

All the underground resources in China are state-owned. However, since the 1980s, as multiple capital system in the mining industry has been progressed, most of actual mining have been done by private-owned (the mining rights of private-owned have gone to subcontractors). Such a separation problem has reached a short-sighted behavior. Actual coal miners have maximized the coal production not only by lowering the ratio of mining which has occurred resource waste, but also by minimizing the costs input which has brought about risky production (as mentioned earlier) [9].

2-(3)-(2). Earning structure on coal resources: financial problems between central and local government

The local governments' attitude to keep unchanged the small coal mines has been closely related with financial problems between central and local government.

In the days of transition in China, the tax sharing system has been implemented. However, that system is done between central government and respective province government. Lower rank local governments than provincial level have still been in the financial contract system (because there are too many ranks of local governments, the author thinks, the tax sharing system cannot be thoroughly implemented). Also the asymmetry problem of financial authority and public service obligation of lower rank local government than provincial level has become more remarkable, and the lower rank local government the more serious financial difficulty (needless to say, the less developed regions like Shanxi province, the more serious).

For the local governments, small coal mines undoubtedly contribute for more tax revenues, more employment opportunities and more GDP growth rate. Moreover, for the basic local governments with serious financial difficulty, it has become the custom to collect donations from small coal mine owners. The basic local governments which are starved for finances and private small coal mine owners who carry the 'original sin' are establishing an unspoken agreement, which is seemed to be a kind of 'reciprocity'.

As regards tax revenues related with energy resources, there are such various kinds of tax as enterprise income tax, resource tax, business tax, value added tax, consumption tax, urban construction tax etc., of which consumption tax is the national tax, but both enterprise income tax and value added tax are the shared tax between central and local. While, resource tax, urban construction tax and other kinds of tax are the local tax. As regards the local tax, however, it is very ambiguous that what the portions of tax revenues among province, cities, prefectures, towns and villages are. The portions vary from one province to another.

It is needless to say the characteristics of energy industry that large scale production is more efficient than small scale. However, in China, it is generally to say that, the larger scale enterprises, the bigger portion of tax payments for higher ranking local governments. Thus, from practical viewpoints of tax revenue maximization, the basic level local governments have never been enthusiastic about larger scale energy industry. We can recognize that, even variety of regulations, lots of small scale coal mines can survive[10].

Both efficiency and safety of energy industry are undoubtedly important. As far as there are serious conflicts on tax revenue allocation between central and local governments, local governments as the administration of actual spots have seemed to be in favor of retaining the small coal mines (branch offices of central government cannot be independent from local government's policy because budget and personnel matters of them are completely regulated by local government). We should recognize thus that it has become the appropriate time to reconsider to reform the 'tax sharing system' started in 1994. It means that it is indispensable for central government and each rank of local governments to secure the finance to meet their responsibility of providing public services[11].

2-(3)-(3). Supervising and regulating system on the coal industry

Fundamental purpose of constitutional politics is to supervise the government's power for protecting the peoples' rights. However, current situation in China has been completely different from that purpose. Even the authoritarian system has given positive influential effects to promote the reform and open door policy, it has nevertheless paid a high price for the effects. From now on, the most difficult problem in China to build a law-governed state is not a difficulty to regulate the people with law, but to regulate the government and bureaucrats with law. The author expects that the dilemma of authoritarian system would become more serious.

In the following of this paper, we would consider the various problems on supervising and regulating system upon the coal industry.

First, because there are lots of sections to supervise and regulate the coal industry, confusion of the system is inevitable. Also, under the authoritarian system, in the following listed sections, some bureaucrats have become corrupted, which has undoubtedly accelerated the 'small coal mines phenomena'. We cannot help recognizing that both falling from power of authoritarian system and invalid governance have become more serious.

Clause four of the 'method on coal resource use in consistent and onerous system in Shanxi province' (187th government ordinance in 2006) indicates as following; the people's governments in more ranked than prefecture are responsible on the coal resource use in consistent and onerous system within the concerned administrative regions. The concerned sections of the people's governments in more ranked than prefecture should be responsible for the following duties, which are,

(1) The land resource section should play the role of unification for the coal resource use in consistent and onerous system. Concretely, the section should confirm the coal deposits, and should register the change of mining rights and levy the mining

costs on related resources.

(2) The coal manufacturing regulation section approves the ability of coal mining production, and should be responsible for initial examination on coal mines construction project after the merger of mines, inspection of the mines after finishing the construction, and issue a coal production permit etc.

(3) Safety inspection section on coal is responsible for inspection on the design of safe facilities at the coal mines construction project after the merger of mines, inspection of the mines after finishing the construction, inspection on safe production conditions on coal mining, and issue a coal production permit etc.

(4) Commerce and industry section is responsible for inspection on the composition of company stocks after changing the holder of mining rights of coal mines by mergers, and preliminary inspection and registration of the name of the company etc.

(5) Finance section is responsible for inspection of revenue on mining rights related costs, and for conversion service of the revenue on mining rights to state-owned stocks and state-owned funds.

(6) Supervising and regulating section on state-owned assets is responsible for supervising and regulating the conversion of the revenue on mining rights to state-owned stocks and state-owned funds.

(7) Administration inspection section is responsible for inspecting the execution of responsibility of concerned administrative organizations and bureaucrats regarding the coal resource use in consistent and onerous system.

Second, there are lots of various kinds of law and regulation from central government and basic local governments. For example, at the HP of energy bureau of National Development and Reform Commission, we can find 11 kinds of law and regulation related with coal[12]. However, in case of coal mine accident, National Supervising Bureau on Safety would announce the new way of view, measure and notification[13].

It means that the main problem is not the absence of law, but the disregarding of law (needless to say, the law in China has never had no problem. For example, generally there are basic rules, but shortages of the laws related with strict procedure are remarkable. Moreover, there have existed the vacuum areas on the law). Then, why can private enterprises have the courage not to follow the law? Under the structure which is said to be the 'government-soot politics' in China, illegal behaviors of private enterprises are adapted to the 'authorized behaviors' of the local government's bureaucrats, who disregard the law. Therefore, private enterprises' behaviors of disregarding the law should be recognized as the systemic problem, not as the problem of private enterprises.

Third, dealing with various problems on coal industry has been dramatically opposed, which have been (1) unintentional and (2) Campaign-style regulation. The mechanism is as follows. Because there is no effective governance when it is normal, outbreaks of accident easily occur. It is also easy to understand that both central government's towering rage and society's repulse have been broken out. Then,) Campaign-style regulation is necessary to appear. It is difficult to think, however, that such regulation can be effective and be sustained.

Fourth, central government has never adopted long-term and stable policy regarding coal, but the policy as regards coal has been always changeable. When coal supply is shortage, regulation becomes loosened up, however, on the other hand, when coal supply is excessive, regulation to small coal mines becomes reinforced. The small coal mines, thus, are trouble makers on the one hand, however, they are victims by easily changed policy on the other.

2-(3)-(4). The problems of censure system

From viewpoints of social contract theory, as the government's power is entrusted by the people, the power should be always supervised. If any unfair exercise of the power is implemented, responsibility of administrative office should be taken through such activities of the Congress as interpellation, impeachment, proposition of the nonconfidence in the Cabinet. It is a censure system, which is made up mainly of the people and the Congress, and the objects of which are needless to say the persons in charge of the administration office concerned.

Recently, in China, the term of 'censure' has been often used. However, the effective forms have done no more than inside the administrative organizations. The upper levels of administration have employed the forms of 'censure' against the persons in charge of the lower level ones (which are like dismissal and filing suit for criminal liability). Besides, no news on the persons in charge has been publicly announced and the persons concerned never have to take their responsibility quite frequently. Furthermore, even if the persons concerned were punished, after the things were cooled off, they were often appointed to other positions. With such realities on the censure system, we can recognize defects of the system inside the administration. Inside the supervision is undoubtedly unreliable.

Essentially, the organization in charge of the censure should be the People's Congress. According to the Article 71 of the Constitution of the People's Republic of China, National People's Congress and the Standing Committee of the National People's Congress can organize an investigating committee on any particular problem when it is necessary. Based upon a report on an investigation, they resolve. At the time when the investigating committee inquires into the case concerned, all of the national organizations, the social associations and the citizens are required to furnish data. However, when such social problems as outbreaks of coal mine accident, food security, wounding and killing of children occur, National People's Congress and People's Congress of respective region has never organize any special investigating committee. In place of it, the censure within the administration has been often carried out. The Chinese people have frequently witnessed the censure, but have never recognized any sign of improvement.

The Chinese style censure with absence of Chinese people is a product of authoritarian system. In order to build a responsible government, systemic transition should be indispensable.

2-(4). Summary

In this paper, the author insists that the important reason of small coal mines phenomena has never been coming from ‘small scale production and obsolete production measures’ (as emphasized by the governments), but coming from systemic factors. It means that, externally, energy consuming development model in China has significant influence, and also internally there are various systemic problems on the coal resource use, both of which have made the small coal mines phenomena out to be prominent social, economic and political phenomena.

From the above viewpoints, the new regulation policy on coal implemented in Shanxi province since 2006 (particularly since 2008) has undoubtedly a limit. First, even the criteria of levying resource costs have been looked over again, the effect of the policy has never been enough. Furthermore, the policy, which has been employed after 2008 and whose main content has been shown as the ‘Guo Jin Min Tui‘, has lots of defects (which are irrational and invalid (see the following section).

3. Instability between government and market: on the new regulation policy on coal in Shanxi province

Since the year of 2006, in Shanxi province, they started the new regulation policy on coal, which has reached till the present. As the first of the policy, they tried to employ the ‘property rights reform of coal mines’ (meaning of reconsideration the criteria of levying resource costs), and, as the second, they formulated the ‘Guo Jin Min Tui‘policy, upon which people discussed heatedly. In the following section, we examine the policy exactly. .

3-(1). The first stage: reconsideration the criteria of levying resource costs and the effects

In February, 2006, in Shanxi province, they promulgated the ‘method on coal resource use in consistent and onerous system in Shanxi province‘ (187th government ordinance), by which they started the onerous system of mining rights before other regions of whole China, based upon the trial and error done previously. According to the ordinance, the resource costs related with mining rights are levied by the quantity of deposits of coal mine and by the quality of coal. Prefecture level governments are responsible for levying the resource related costs, however, the levied resource costs are allocated among province, city and prefecture with the ratio of 3:2:5 respectively.

As a matter of fact, compared with the market price of coal at present (around 300 yuan per ton), the amount of the resource costs related with mining rights (about 3 yuan per ton) are extremely small[14]. According to practical customs, when coal industry is reorganized, local government closes down the small coal mines with a fixed ratio as requested. Remained coal mines are not so different from the closed ones as regards the production size and production measures. Coal mine owners believe that they can make a large profit in 1~2 years with all their powers when coal industry is booming. The destructed pattern of resource mining has never been changed easily.

3-(2). The second stage: aim of 'Guo Jin Min Tui' policy

The main points of a series of policies named 'Guo Jin Min Tui' have been decided in the two official documents of 2008 and 2009, which were (1) 'on the view of implementation for Shanxi province government to accelerate the mergers and reconstructions of coal enterprises' (23rd official document), and (2) 'on the notice for Shanxi province government to promote the mergers and reconstructions of coal enterprises' (10th official document). Thus, the central task of the series of policies is to seek safety and efficiency.

There is no expression of 'Guo Jin Min Tui' in those documents, but undoubtedly it is correct to say that, when Guanxiao Jianda(関小建大) policy (indicating 'to close down the small coal mines and to construct the large coal mine enterprises') is implemented, private enterprises' possibility to survive becomes quite limited.

The policy is implemented by the way of taking apart. Main organizations to put the policy into effect are respective city and prefecture, and state-owned important coal mining enterprises. Although the respective local organizations can establish concrete implementation plan voluntarily, The 'leadership group of the adjustment policy on mergers and reconstructions of coal mining enterprises', which is founded by the province government, finally decides. .

According to the prescriptions, the new regulation policy on coal is more centralized and practical process of the policy is in a top-down way.

Various reforms both of major and minor need inevitably the adjustment of benefit allocation. Because the new regulation policy on coal in Shanxi province was put into operation in a short time, the necessary adjustment was especially difficult. In the following section, winners and losers at the benefit acquisition arena are considered.

3-(3). Losers at the benefit acquisition arena

3-(3)-(1). Wenzhou merchants as small coal mine owners

As the first loser, small coal mine owners should be listed.

Under the new regulation policy on coal, small coal mine owners have two choices, which are (1) to sell the coal mines and (2) to be stockholders. In the former case, they are afraid of lower appraised value of the assets, and, in the latter case, as they cannot become large stockholders, they cannot participate in management. Lots of private investors do not put confidence in efficient management of state-owned enterprises, and the majority of them prefer the former than the latter.

In particular, the circumstances of small coal mine owners were paid attention, of which many Zhejiang merchants (Wenzhou merchants, above all) were included.

3-(3)-(2). The negotiation between Zhejiang province and Shanxi province and

the influence regarding the case

With facing the situation mentioned above, Zhejiang province government could not say nothing. Various levels of government and governmental organizations in Zhejiang province have tried to negotiate with Shanxi province with every possible means. However, up to now, the Zhejiang province's attempts have never been successful.

Even the new regulation policy on coal is beneficial for Shanxi province (meaning that, by improving safety and efficiency, the occurrence ratio of accidents is decreased and the supervising responsibility of Shanxi province government is alleviated – this is a theory but not a real -), there are undoubtedly still risky. Such regional protection policies as the 'merger and acquisition policy' have lost not only the benefit of private owned enterprises and other provinces, but also credibility of Shanxi province because of instability of investment policy. It is inevitable that private investors' evaluations on the investment environments decrease.

Arbitrariness on the policy decision is closely connected with the person-governed society, which undoubtedly raises the transaction costs. Those tendencies are undoubtedly negative for the promotion towards market oriented economic system.

3-(3)-(3). Lower ranked local governments than province and local governments' bureaucrats

As mentioned previously, the tax sharing system of 1994 has been implemented after all between central government and province level government. Lower ranked local governments than province have still taken the finance contract system. As regards enterprises, their tax payments are also classified into province, city, prefecture, township, village, according to the size of enterprises. Thus, compulsory merger and acquisition of small and medium scale enterprises by state-owned large scale enterprises has never been desirable for lower ranked local governments than province. Before the new regulation policy on coal was put into effect, some local governments made small coal mines inside their prefecture merged voluntarily. By such mergers, those small coal mines could not be merged by large scale enterprises from outside source.

At the same time, local governments' bureaucrats might be said as the losers in a certain sense. As was said earlier, in order to open the coal mining business, complicated procedures are indispensable. When the merchants apply the administrative procedure, bribery affairs are quite usual. It is said that, in order to have a complete set of various permits, they need five million yuan[15]. Besides, it becomes popular that bureaucrats buy stocks in small coal mines (Guangu- bureaucrats' stocks-). The new regulation policy on coal, the purpose of which is to eliminate the small coal mines, might have significant effect on those bureaucrats (having a cozy relationship with merchants).

3-(3)-(4). Coal mine workers

The coal mine workers, who have originally employed informally, were never referred at all when the 'Guo Jin Min Tui' policy was considered. They might lose automatically their jobs. The main characteristic of Chinese development model which is shown as 'peoples' absence' occupies important position in the new regulation policy on coal.

3-(4). Winners at the benefit acquisition arena

3-(4)-(1). Large scale state-owned coal enterprises in Shanxi province

The 23rd and 10th official documents of Shanxi province government have limited to eight enterprises for merger and acquisition. Those eight large scale state-owned enterprises originally have their spheres of influence, based upon which the areas of merger and acquisition are clearly allocated. Even central government has been influenced by Shanxi province government, which could thus formulate a strong regional protection policy.

In order to save the energy costs, power stations inside the Shanxi province purchased the coal from private-owned small coal mines (it is usual however that large scale coal enterprises inside the province sell the coal at a high price to the market outside the province). Due to the new regulation policy on coal, all the private-owned small coal mines inside the province went bankrupt. As the result, in the winter of 2009, power stations inside the Shanxi province suffered from coal shortage, which had to ironically purchase the coal from outside the province at a higher price .

3-(4)-(2). Shanxi province government

As a formulator of the policy concerned, Shanxi province government has expected the policy effect to improve the safety and efficiency of coal industry inside the province. If the policy effect can be actually realized, executive members of the province government, who have often deserved censure at the time of coal mine accidents, can secure their 'political safety'. However, the reliability to say that the state-owned enterprises can improve the safety and efficiency is doubtful. The coal mine accidents occurred after 2008 in Shanxi province have included the cases of state-owned large scale enterprises. Because China still has the systemic problems, we cannot assume that, as they are large scale enterprises, there is a little likelihood of causing accidents. Also a proposition saying that the management of state-owned enterprises is more efficient is rejected by the 30 years' experience in China (after the reform and open door policy). As a matter of fact, lots of private-owned small scale coal mine owners have chosen to sell their coal mines as they do not put confidence in efficient management of state-owned enterprises.

Shanxi province has been the biggest coal production base of the whole China. It is occasionally pointed out that one of the purposes of 'Guo Jin Min Tui' policy in Shanxi province is to control the coal price in Chinese domestic market by governmental intervention. During the Chinese experience of high speed economic growth and of energy consuming type production, profit rate of coal industry has been higher (if not, lots of private capital from outside provinces would have never been invested).

3-(5). Chinese systemic transition towards market oriented system: on the trend of 'Guo Jin Min Tui'.

3-(5)-(1). Recent trend of 'Guo Jin Min Tui'.

In February 24th, 2005, Chinese Cabinet made public the well known document entitled '36 articles on the non-public-owned economy' (some suggestions for the development of non-public-owned economy to encourage, support and instruct). However, in five years after then, development of private owned economy in China has never been successful. (Table 2 indicates the recent trend of 'Guo Jin Min Tui'. It seems to clarify that the financial crisis of 2008 has formed the serious transformation).

In the year of 2008, which shows that 30 years have passed after the beginning of reform and open door policy, the financial crisis occurred. In order to stimulate the economy, Chinese government invested 4,000 billion yuan (around 590 billion US$) in the 'ten major industries for promotion'. As the result, undoubtedly, the position of state-owned sector in Chinese national economy has been reinforced, which could be recognized as a kind of policy effect of the 'Guo Jin Min Tui'. It automatically means that more investment amount for infrastructure construction and heavy industries indicates less investment for such private-led sectors as service and light industries. That is to say, based upon the financial crisis, ability to control the resources by state-owned sector has been strengthened. Those situations have seemed to us that the general tendency towards market oriented system has been reversed.

As Table 2 points out, not only the new regulation policy on coal in Shanxi province, but also the merger and acquisition of private enterprises became a boom. (Financial crisis seemed to be a good reason).

Then, in March, 2010, the Standing Committee of Chinese Cabinet newly emphasized the plan to decrease the entry barriers for private enterprises to start a new business and to entry in reorganizing the state-owned enterprises. The Prime Minister, Wen Jiabao, has appealed the necessity of structural reform and relocation of national economy in addition to reconsider the investment criteria and investment fields in order to deregulate the investment by private-owned in such monopolized industries of state-owned enterprises as telegraph, public service, science and engineering industry of national defense, social security type housing construction. The purposes of the decision carried out in March, 2010, thus, have been (1) stimulation policy for economic reconstruction (towards expansion of domestic consumption and structural adjustment) and (2) central government's correspondence to the 'Guo Jin Min Tui' policy, which has become a hot issue among academic experts since 2008.

3-(5)-(2). Two indispensable policies towards market oriented system

There are two indispensable policies to promote the market oriented system. (1) First, in the aspect of economic system, both promotion of privatization and protection of private property rights are necessary. (2) Second, in the aspect of political system, establishment of constitutional system is necessary. The former is the important necessity to assure the mechanism of market competition, and the latter is also the important necessity to prevent the erosion of power. For the moment, the argument discussing that, Chinese market economy has become the ‘privileged capitalism’, has been paid attention, and we should consider once again what the sound mechanism of market oriented system is all about.

4. Conclusion: to remember the Shanxi province at the Jinshang(晋商) era

The purpose of this paper is to examine the questions asking why ‘small coal mines phenomena’ have occurred, what ‘small coal mines phenomena’ have suggested. By investigating the above questions, the author has above all tried to consider the course of systemic transition in China.

Phenomena related with ‘small coal mines’ are such various ones as outbreak of accidents, environmental pollution, waste of resources, and corruption of government officials. It means, therefore, that ‘small coal mines phenomena’ can be said as a giant scale ecological system, in which such various problems as political, economic, environmental, cultural have coexisted complicatedly.

Shanxi province government has emphasized the ‘small-scale production’ and ‘outdated way of production’ as the reasons of occurrence of ‘small coal mines phenomena’. However, in this paper, author would like to pay more attention upon other two systemic reasons; (1), as the external aspect, ‘energy consuming development model in China’ and (2), as the internal aspect, ‘various systemic problems on coal resource utilization’, which have involved complicatedly. Thus, the ‘small coal mines phenomena’ coming from the ‘small-scale production’ and ‘outdated way of production could be interpreted as the results of the above internal aspect.

In the regional studies, the sustainable development is the most important and the most fundamental task to be investigated. As regards the economic development in Shanxi province, are such series current problems upon development, which have been, for example, industrial structure problem depending upon coal, the ‘small coal mines phenomena’ and the decline problem to be a ‘resource exhausted city’, inevitable results? When the history of ‘Jin Shang‘ (Shanxi merchants) is looked back upon, it is clear that they might not be inevitable.

In this paper, the author calls the incorporated development model in development strategies the ‘endogenous development model’ and the independent development model from development strategies the ‘exogenous development model’. In that sense, the author could not help saying that the economic development model in Shanxi province which has been suffered from the ‘small coal mines phenomena’ and the ‘Guo Jin Min Tui‘ is still at the stage of ‘exogenous development model’.

Notes

1. See National Development and Reform Committee (2007), *The Eleventh Five Years Plan*, January.
2. Chen, Yun and K. Morita (2009), "Goods Production in Shanghai and Garbage Production in Zhejiang: The Shanghai Model and the Zhejiang Model in the Chinese Recycling-Based Economy" (in Japanese), *The Hiroshima Economic Review* (in Japanese), Vol.33, No.1.
3. Chen Yao(2007), "The Prospects for the Chinese Coal Industry: An Analysis on the Policy and the price" (in Chinese), *Energy in China* (in Chinese), Vol.9.
4. Zhou Jianjun (2007), "Shanxi province: curses on resources should be removed ASAP" (in Chinese), *Chinese reform*(in Chinese), Vol.3.
5. Zhang Lianlian (2007), "A consideration on the property rights reform of coal mines in Shanxi province" (in Chinese), *Chinese coal industry* (in Chinese), Vol. 2.
6. A Xiang (2005), "A flood of bloody black money and a misfortune" (in Chinese), *Town and Village Enterprises in China*, (in Chinese), Vol.12.
7. Chen, Yun (2009), *Transition and Development in China: Towards Shared Growth*, Farnham, Ashgate Publishing.
8. Li Beifang (2006), "Troubles on coal mining rights" (in Chinese), *Windows for the south breeze* (in Chinese), Vol.21.
9. Zhang Lianlian (2007), "A consideration on the property rights reform of coal mines in Shanxi province" (in Chinese), *Chinese coal industry* (in Chinese), Vol. 2.
10. Bao Quanyong、Su Ming、Fu Zhihua (2006), "A proposal about the finance and tax reform in energy of the central and the local government" (in Chinese), *Economic Studies Review* (in Chinese), Vol.14.
11. See Chen, Yun (2009), *Transition and Development in China: Towards Shared Growth*, Farnham, Ashgate Publishing.
12. As regards the coal related law, there are such eleven laws as 'security law on the mines in People's Republic of China', 'enforcement ordinance of security law on the mines in People's Republic of China', and 'regulation about the supervising of coal production license'. See the HP of Energy Office of National Development and Reform Committee.
13. Such announcements as of coal related policy include 13 chapters like systemic mechanism, supervising the industry, project plan, searching and mining, production management, business management, safety management. See the HP of National Safety Supervising Office.
14. Li Beifang (2006), "Troubles on coal mining rights" (in Chinese), *Windows for the south breeze* (in Chinese), Vol.21.
15. Xia Yang (2009), "The social background of 10 billion black money for the reconstruction of Shanxi coal industry" (in Chinese), Phoenix *Weekly*, (in Chinese), Vol.31.