

Price-endogenized Inter-industry Approach with Goods and Bads¹

by

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Abstract

Being used by local governments in many regions of Japan, the industrial waste-disposal tax is thought to contribute a restraining effect in reducing the environmental burden. However, whether this tax alone is effective and, if so, how much the tax rate should be among the controversial questions need to be solved. Based on the advancement in recycling technology and the importance of demand side management from a material-cycling viewpoint, moreover, it is extremely important to introduce the appropriate methodology for determining the optimal policy among the proposed alternatives. The present paper proposes a computable general equilibrium model emphasizing on the framework of the waste input-output concept and thoroughly describes material and current flow among economic sectors. Finally, we apply the proposed model to environmental scenario, accounting for the waste disposal tax and its economic and environmental effects.

Keywords: Waste disposal tax, Industrial waste, Municipal solid waste, CGE model, Policy implication

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1 Introduction

In Japan, domestic recycling system has been increasingly promoted as a way to cope with the environmental problems involving energy consumption, global warming, and waste disposal resulted from both consumption behavior of the household sector and production behavior of the industry sector. Such recycling system is based on a scenario in which new raw materials are saved by actively using recycled materials under the recycling strategy, and thus eliminating energy consumption and carbon dioxide emission that could have resulted from the production of those new raw materials.

In recent years, despite the growing consciousness in favor of waste reduction, reuse and recycling, there is still no consensus as to what extent we should achieve these goals, who should implement the plan, and how they should be done. In this respect, we could therefore say that the waste management policy designed to achieve the goal of a sound material-cycle society still remains in a state of trial and error.

In 2000, the total household waste emission² in Japan amounted to 52.36 million tons. That translates to waste emission per capita per day of about 1.132 kilograms. Part of the refuse was sorted and then collected from all municipalities to be recycled.

Combined with the recyclable wastes that were processed through the intermediate treatments, they amounted to 5.09 million tons. On the other hand, the recycling waste called-back by registered resident groups under the subsidy from municipalities was 2.77 million tons. In total, the recycling waste of 7.86 million tons represents a recycling ratio³ of 14.3%. Summing together the direct land-filled wastes and the final disposed wastes after intermediate treatments yields the total land-filled wastes of 10.51 million tons. At the end of 2000, there were 2077 facilities used as dump yards for final disposal of general wastes. The remaining landfill capacity was 157.2 million m³, which was estimated to last about 12.2 years⁴.

For the industrial wastes, the circumstances are more severe. In 2000, the total discharged wastes were 406 million tons. Among these, 184 million tons (45.3%) were recycled and 45 million tons (11.1%) were land-filled. There was only 176.1 million m³ available as the remaining landfill capacity, giving an estimated 3.9 years of industrial waste landfill capacity⁵ (Ministry of the Environment of Japan, 2003a).

² Total waste emission = Collected garbage + Directly brought-in garbage + Home-disposed garbage. Base on the waste-disposal law, the amount of general waste-disposal is calculated by subtracting "Home-disposed garbage" from the total waste emission and adding "Recycling waste called-back by registered resident groups". Using this definition, the emission amount in 2000 is 54.83 million tons.

³ Recycling ratio (%) = $\frac{\text{Total recycling waste}}{\text{Total waste emission}} \times 100 = \frac{5.09+2.77}{54.83} \times 100 = 14.3\%$

⁴ Remaining year = $\frac{\text{Remaining landfill capacity up to the end of fiscal year}}{(\text{Total general landfilled wastes}/\text{Relative density of landfilled wastes} = 0.8163)}$

⁵ Remaining year = $\frac{\text{Remaining landfill capacity up to the end of fiscal year}}{\text{Total industrial landfilled wastes}}$.

Consider the relative density = 1.0

As the increase tendency in quantity of discharged wastes could be expected from the rapid growth of international trade and world economics, the capacity of final waste disposal will be tightly pressed. Various kinds of environmental issues will certainly arise. Consequently, it is essential to construct an efficient system of product recycling circulation in Japan.

In order to reduce environmental externalities from industrial activities and our consumption lifestyles in a community, appropriate policy instruments aiming at minimizing emission and closing material cycles are necessary. In Japan, the industrial waste disposal tax is the first environment tax enforced under the anticipation that it help, to some extent, control the environmental burden released from industrial wastes.

Moreover, considerable attention has been centered recently on the hypothesis that taxes imposed on polluting activities yield a double-dividend in that it helps not only to protect the environment but also to raise revenue that can be used to reduce other distorting taxes (Bovenberg and de Mooji, 1994; Goulder, 1994).

However, whether this tax alone is effective and, if so, how much the appropriate tax rate should be are among the controversial questions need to be solved. Moreover, based upon the advancement in recycling technology and the importance of demand and supply side management from a material cycling viewpoint, it is important to introduce an appropriate method for determining the optimal policy among the proposed alternatives.

Even though there is an evident chain consisting of production, consumption, waste generation, and waste disposal (or recycling), the decision making at each link along the path is performed in isolation from the other. This mechanism impedes the conscientious recycling of potential resources contained in wastes. For this reason, it is essential to establish cooperation in forms of social systems that regulate the flow of goods and bads from an environmental viewpoint through the processes of manufacturing, consumption, waste generation, and final waste disposal or recycling. Economic instruments for restraining final waste disposal and promoting recycling are some of the tools to attain such formation of social systems.

In this paper, we develop a computable general equilibrium model so that it can explicate the transaction between the entire production activities of goods and waste disposal services and the corresponding household consumption behavior. The mathematical model and database developed in this research make it possible to examine the proposed environmental scenarios in order to accomplish a material cycle sustainable society.

We start from a general idea concerning the overview of economic structure and data structure of the production sector, emphasizing on the basic framework with the waste input-output concept describing a fundamental material and current circular flow among economic sectors. This is followed by mathematical expression of model's structure to give more details about the production and demand specification, and also how equilibrium conditions are characterized. Finally, we apply the model to the proposed scenario, particularly accounting for the waste disposal tax and its economic and environmental effects.

We draw several important originalities from this CGE model. Firstly, it takes into account the waste generated from virtually any waste source in the economy, including municipal solid wastes (MSW) from final demand sectors, industrial and com-

mercial waste from the goods- and services-producing sectors, and treatment residues from waste treatment sectors. It also encompasses the entire life-cycle of each product from the production to consumption, disposal, and recovery and captures each price paid along the way, so taxes or other policy instruments imposed at one stage have their equivalent counterpart at another stage. Secondly, in a case where industries use the available production technologies and jointly generate the waste, a product-mix structure within the activity framework needs to be introduced. Based upon the MAKE-USE framework, the model captures the facts that goods and services industries produces not only ordinary goods and services but also waste treatment services, while waste treatment service industries dispose of wastes and then recycles them into products. Thirdly, the model expresses the correspondence between the waste treatment technologies and the intermediate waste inputs taking into account the dynamics of waste management, by incorporating an engineering process of waste treatment through the allocation matrix.

The present paper is organized as follows. First, as a basis for comparison, we review the related literatures in the next section. In section 3, a mathematical model is formulated, followed by a discussion of the Walras's law and equilibrium conditions in section 4. Section 5 describes the economic accounts and a basic structure appropriate for computable general equilibrium analysis and a micro-consistent benchmark data set. We show the results from model simulation under the proposed scenarios in section 6. Finally, section 7 concludes the paper.

2 Literature Review

To evaluate the merit of the system of product recycling circulation society, it is necessary to make clear the demand-supply balancing structure accompanied by the ability to estimate the waste quantity excreted by each industry and household. The crucial starting point aim at waste disposal policy analysis is the development of the Waste Input-Output (WIO) model (see Nakamura, 1999; Nakamura and Kondo, 2002; Kondo and Nakamura, 2004). The WIO model describes how different types of waste are generated and treated by different technologies in a research framework that is widely acknowledged among the industrial ecologists. Kondo and Nakamura (2005) present a decision analytic extension of the WIO model. The model is extended in several directions and the authors present another extension using Linear Programming (LP) to identify the waste management and recycling strategy that maximizes 'eco-efficiency' potentials subjected to technological and resource constraints.

Kagawa (2005) explores another extension of the WIO model and introduces the extended input-output framework by Miyazawa and Masegi (1963) to WIO model where income distribution, household consumption and household waste production are explicitly accounted for. The study by Miyazawa and Masegi (1963) interconnects household sectors with inter-industry accounts, opening a variety of new possibilities of addressing the effect of demographic changes, the rebound effect, income inequalities and household consumption patterns that are of great interest in industrial ecology. Kagawa (2005) not only presents a thorough theoretical basis for the household endo-

genized WIO model but also demonstrates the applicability and the usefulness of the model with a case study.

Takase et al. (2005) introduce the augmented framework with the structural relationship representing the dependence between household consumptions and household waste generations. This framework is every useful in analyzing the consumption rebound effects. Takase et al. (2005) also estimates CO₂ emission and landfill consumption induced by household consumption. They empirically evaluated sustainable consumption scenarios, such as shifting transportation mode from a private car to public transportation and the longer use of household electric appliances.

In the environmental taxation aspect, Pigou (1920) first suggests a direct tax on waste, at a rate equal to marginal external damages, as an efficient method of controlling pollution. As a practical matter, however, enforcement of this tax may not be feasible, for example, due to the possibility of inducing illegal dumping or burning. Research by Russell, et al (1986), also indicates that the U.S. government monitoring and enforcement activity is quite low.

Fortunately, alternative incentive-based methods that retain many of the properties of a direct tax while minimizing the need for monitoring and enforcement. A practical example is a deposit-refund system (Fullerton and Kinnaman, 1995, 1996; Kinnaman and Fullerton, 2000) on items such as glass bottles and aluminum cans. The two-part instrument (2PI) is a generalization of a deposit-refund system, however, because it can be used to address other types of pollution. The tax and subsidy do not have to apply at the same rate, to the same commodity, or even to the same economic agent (Fullerton and Wolverton, 2005). Palmer and Walls (1997) also discuss combination of instruments, and Walls and Palmer (2001) provide the closed-form solutions for the first-best two-part instrument that exactly matches the incentive effects of a direct tax on pollution or waste. If taxing the upstream pollutants is feasible, for example, then Pigovian emissions taxes along with a combined output tax and recycling subsidy will generate the social optimum.

Regarding CGE-based models for environmental analysis, Masai et al. (2000) construct a dynamic model in which the economic activities and their related environment burden are integrated and evaluate the economic impact of imposing the constraint on carbon emission and final waste disposal. However, their model does not explicitly formulate the government sector's behavior. Tax system analyses, therefore, cannot be implemented effectively due to the lack of macro-level I-S balance constraint. In this model, moreover, the production technology of the pollution abatement inputs is not available. This implies no price-responding interaction to the supply-side behavior can efficiently be analyzed. Finally, although household wastes are handled, no disposal service is required under the budget constraint causing a free disposal propensity.

Kawase et al. (2003) extend the pioneering model of Hashimoto and Uemura (1997) and Hashimoto and Oh (2002) to study the possibility of achieving double dividend by applying a carbon tax together with a reduction in other taxes to Japanese economy through several scenario analyses. A similar static CGE study is presented by Felder and van Nieuwkoop (1996) as well as Felder and Schleiniger (2002). However, these models do not take the disutility of environment externality, i.e. carbon emission level, into account. Their results regarding the double dividend are hence more or less over- or underestimated.

Okushima (2004) proposed two independent models to study the economic impacts of global warming policy and waste-recycling policy. His models are aimed to analyze the change in not only the effectiveness but also the equity of implementing environmental tax policy to each sector of the economy. However, the assumptions used in each model are unconnected. The CO₂ cut-back effect and the final waste disposal reduction effect of each production sector are thus not able to be integrated. To evaluate these effects in more efficient way, it is essential to incorporate both schemes into one consistent model. With regard to the waste disposal tax imposition, Okushima put this tax not only on the final disposal but on all kinds of wastes, including recycled ones. This obstructs the study on waste recycling promotion effect and should be treated separately instead.

Being the first environment tax actually put into practice in Japan, the waste disposal tax and its contribution to waste recycling encouragement are thoroughly studied using a coherent CGE model in Washida (2004). The possibility of evading the utility loss due to tax imposing through a tax revenue neutralization scheme is also verified. However, some theoretical problems associated with his model can be noted. Firstly, despite the natural difference in treatment methods among 18 types of industrial and household wastes presented in this model, there exists only one waste disposal sector responsible for all recycling services and final disposal service without intermediate treatments. Secondly, all recycling services and final disposal service have a constant price with no explicit production technology. Thirdly, the ratio of waste to be recycled and final disposal waste to the total production of any industry are fixed, not allowing producer to choose how much he/she is willing to recycle the total waste emission corresponding to the market service prices. Fourthly, unlike Masai et al. (2000) and Okushima (2004), Washida's model treats recycled goods as perfect substitutable to primary/ordinary inputs. Finally, the product mix nature of production technology considering by-product and recycled goods as secondary products is ignored.

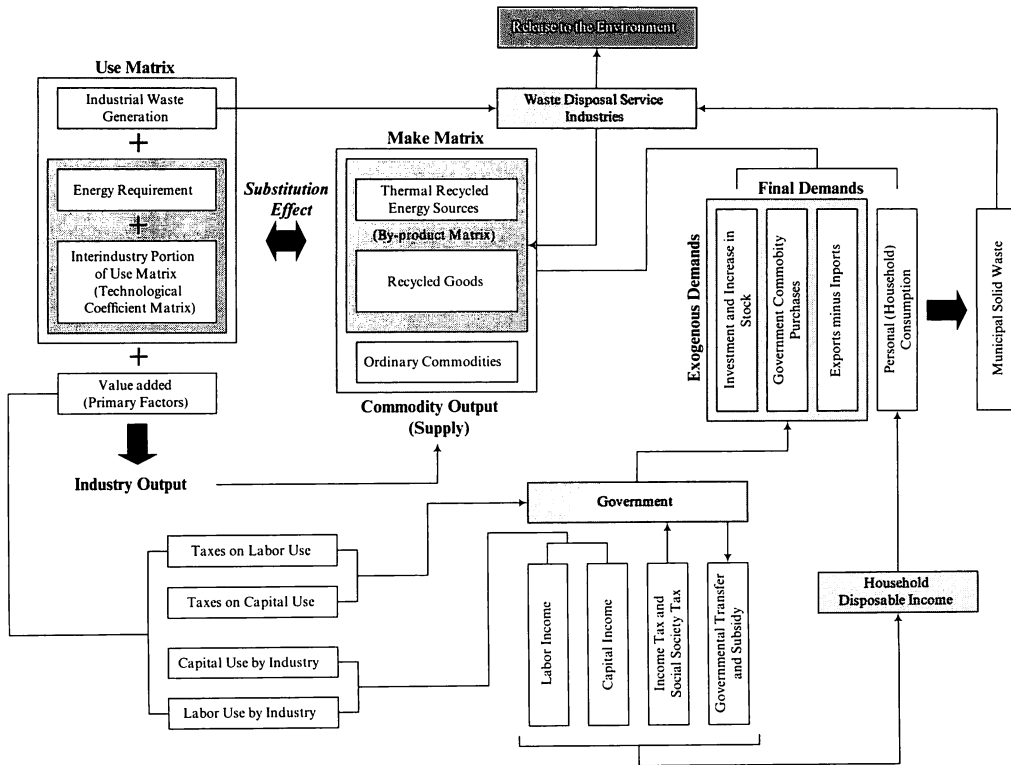
Centered around these range of existent works, this paper try to develop an elaborate environment-integrated CGE model using the 1995 WIO database as a reference point. Our model contains many points that cannot be tackled using pre-existing models. First, based on the MAKE-USE framework, secondary products such as by-products from goods and services industries and recycled goods from waste treatment service industries can efficiently be handled with price-responsive production technology. Second, the model allows the intermediate waste treatments through the allocation matrix expressing the correspondence between the waste treatment technologies and the intermediate waste inputs. Third, we incorporate the substitution between the ordinary and recycled intermediate inputs/energy inputs into the model with explicit demand-supply market clearing conditions to study the recycle-inducement effect of taxes or other policy instruments. Fourth, the model can be furthered modified to cope with a deposit-refund system or a two-part instrument designed to avoid the possibility of household illegal dumping. This is done by setting all waste disposal prices to be zero and taxing commodity consumption with the appropriate consumption tax rate.

The effectiveness of implementing a deposit-refund system in the real economy with disaggregate consumption goods, pre-existing distortionary taxes, and substitution behaviors between recycled and virgin materials or energy inputs is also verified. Readers should refer to Bunditsakulchai (2006) for further mathematical details.

3 The Model

In what follows, we describe the large-scale CGE model emphasizing linkages among sectors and consumer of the national economy. The model provides a comprehensive framework to analyze the structural effects of federal environment policies. Figure 1 shows an overview of the economy⁶. Based on the commodity technology assumption that there exists an industry mainly producing the concerned commodity by means of a well-defined production technology, all production technologies are separated into m goods and services technologies, n energy-related producing technologies and waste

Figure 1: The structure of economy



⁶ To simplify the diagram, taxes levied on emission and/or discharge from the production process and the household consumption, taxes levied on the energy input and taxes or subsidies on the virgin and recycled material inputs.

⁷ We assume that, in this model, there are q types of industrial and household municipal solid wastes need to be disposed of by p waste treatment technologies. The share of industrial waste k disposed of by the waste treatment technology i , S_{ik} , is represented by the industrial allocation matrix $S_1 = (S_{ik})_{i=1, \dots, p; k=1, \dots, q}$. The household allocation matrix $S_2 = (S_{ik})_{i=1, \dots, p; k=1, \dots, q}$ shows the share of household waste k that is treated by treatment method. See also Nakamura, S. and Kondo, Y. (2002) for the further detail about this concept.

treatment technologies⁷. This model also introduces a product-mix structure within the activity framework where industries use the available production technologies and jointly generate commodity outputs and wastes. All industries are categorized into m goods and service industries, energy-related industries and p waste treatment service industries. Furthermore, this procedure implicitly presumes that any waste treatment service industry mainly uses one of the available waste treatment technologies. Practically, the main waste treatment service can be identified from the waste treatment activities levels in physical and monetary base.

3.1 Production sectors

3.1.1 NCES (Nested Constant Elasticity of Substitution) system of the production function

Industrial technology production function is represented by a multi-level production process as shown in Figure 2. The top level process consists of a Leontief production function in which intermediate input is combined in fixed proportions with other intermediate inputs and extended value-added. At the intermediate level, industries substitute among a primary factor value-added input — capital and labor, a total energy requirement input and a total waste disposal service input. At the bottom level, we also allow for the substitution between the virgin and the recycled materials or by-products within the intermediate input components and between the original energy sources and the recycled ones.

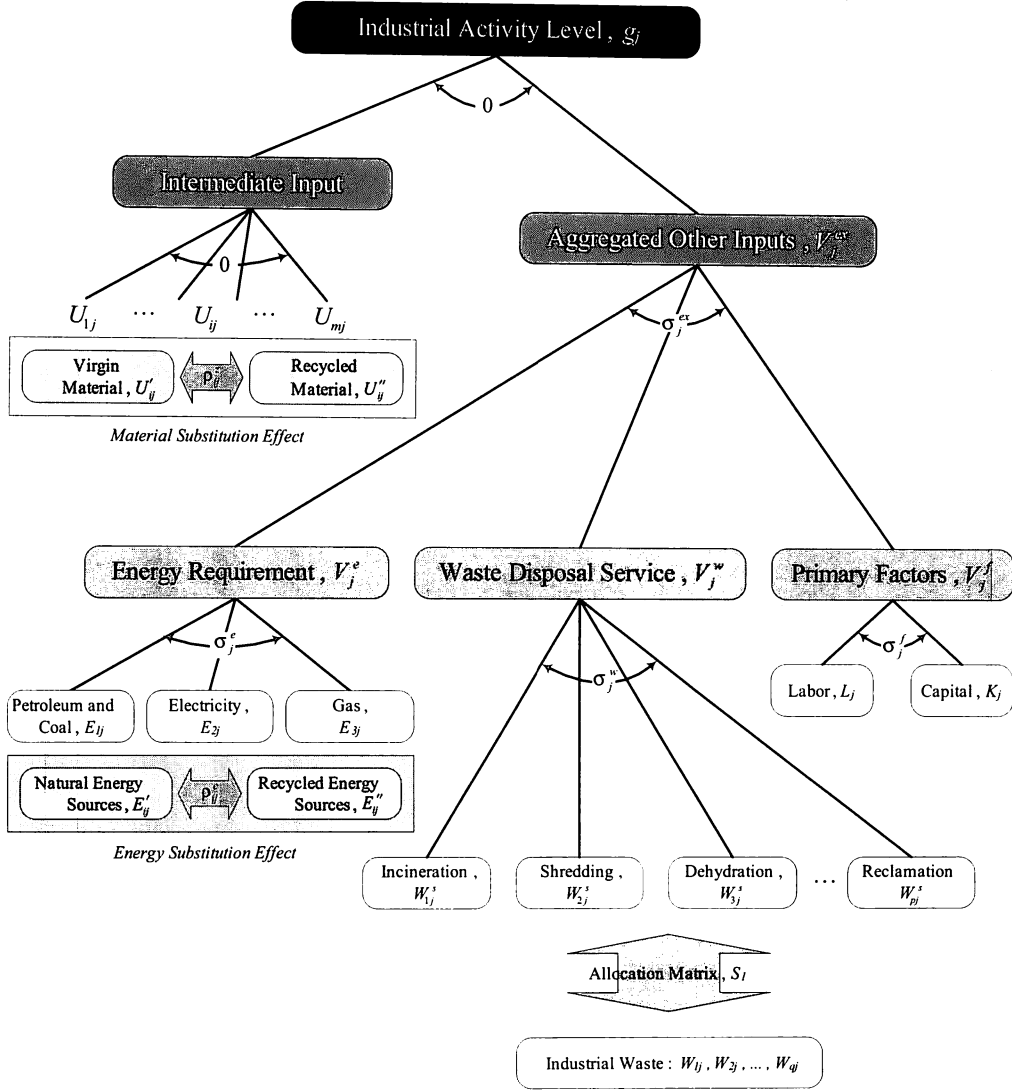
The activity level of j^{th} ($j=1, \dots, m+n+p$) production sector expressed in a monetary value, g_j , is given by the Leontief-typed production function $g_j = \min (U_{ij}/b_{ij}, \dots, U_{ij}/b_{ij}, \dots, U_{mj}/b_{mj}, V_j^{\text{ex}}/b_j^{\text{ex}})$ with the intermediate inputs of commodity from industry j , U_{ij} , the aggregated input other than intermediate input, V_j^{ex} , involving a primary factor value-added input, a composite energy input and a composite waste disposal service input, the fixed coefficient of aggregated other inputs, b_j^{ex} , and the intermediate input fixed coefficient, b_{ij} , which is the element in the use matrix⁸:

$$\mathbf{B} = \begin{bmatrix} b_{1,1} & \cdots & b_{1,m+n+p} \\ \vdots & \ddots & \vdots \\ b_{m+n+p,1} & \cdots & b_{m+n+p,m+n+p} \end{bmatrix}.$$

Underlying this function is the assumption that intermediate inputs and an aggregated other inputs are weakly separable. The assumption of such separability permits the optimal combination of components in an aggregated other inputs to be determined apart from the intermediate inputs decision.

The aggregated other inputs function is represented by the CES technological relationship combining primary factor inputs, V_j^f , a composite energy input, V_j^e , and a com-

⁸ Here, the intermediate input fixed coefficient derived under the mixed technology assumption and waste treatment technology assumption is completely different from the input coefficient a_{ij} of ordinary IO model calculated by simply dividing the monetary value of flow from sector i to j by total production of sector j , X_{ij}/X_j . Please refer to Kagawa et al. (2003) for more information about the assumptions used in this model. The derivation of b_{ij} is presented in detail by Bunditsakulchai (2006).

Figure 2: Production function and substitution elasticity


posite waste disposal service input⁹, V_j^w , with a scale parameter θ_j^{ex} , the elasticity of substitution σ_j^{ex} and the share parameter $\alpha_j^{ex,f}$, $\alpha_j^{ex,e}$, $\alpha_j^{ex,w}$ for primary factor inputs, a composite energy input and a composite waste disposal service input, respectively.

$$V_j^{ex} = \theta_j^{ex} \left\{ \alpha_j^{ex,f} (V_j^f)^{\frac{\sigma_j^{ex}-1}{\sigma_j^{ex}}} + \alpha_j^{ex,e} (V_j^e)^{\frac{\sigma_j^{ex}-1}{\sigma_j^{ex}}} + \alpha_j^{ex,w} (V_j^w)^{\frac{\sigma_j^{ex}-1}{\sigma_j^{ex}}} \right\}^{\frac{\sigma_j^{ex}}{\sigma_j^{ex}-1}} ; \alpha_j^{ex,f} + \alpha_j^{ex,e} + \alpha_j^{ex,w} = 1$$

The demand function for a composite energy input, a composite waste disposal service

⁹ In Washida (2004), only a final waste disposal is taken into account here. We, however, allow producers to choose among various alternatives of disposal technology what suits their wastes with regards to the market price of each choice.

input and primary factor inputs per unit of aggregated other inputs, V_j^{ex} , are determined by $\min_{\{V_j^f, V_j^e, V_j^w\}} P_j^{ex} V_j^{ex} = P_j^f V_j^f + P_j^e V_j^e + P_j^w V_j^w$ subjected to the above production technology constraint, giving:

$$v_j^s = \frac{V_j^s}{V_j^{ex}} = \frac{1}{\theta_j^{ex}} \left\{ \alpha_j^{ex,f} \left(\frac{\alpha_j^{ex,s} P_j^f}{\alpha_j^{ex,f} P_j^s} \right)^{1-\sigma_j^{ex}} + \alpha_j^{ex,e} \left(\frac{\alpha_j^{ex,s} P_j^e}{\alpha_j^{ex,e} P_j^s} \right)^{1-\sigma_j^{ex}} + \alpha_j^{ex,w} \left(\frac{\alpha_j^{ex,s} P_j^w}{\alpha_j^{ex,w} P_j^s} \right)^{1-\sigma_j^{ex}} \right\}^{\frac{\sigma_j^{ex}}{1-\sigma_j^{ex}}}, \quad (1)$$

which applies for $s = f, e$ and w .

Capital K_j and labor L_j inputs together form a primary factor value-added that is produced subject to the CES technology with a scale parameter θ_j^f , the elasticity of substitution between capital and labor inputs σ_j^f and the share parameter α_j^f . By taking into account the industry output tax and the appropriate markup rewarding the true cost of commodities absent from the model for a given price elasticity of primary input demand, the cost minimization $\min_{\{K, L\}} P_j^f V_j^f = (1+\tau_j^f)(1+m_j) \left((1+\tau_j^k) r K_j + (1+\tau_j^l) w L_j \right)$ is performed so as to determine the factor demand of capital and labor as:

$$k_j = \frac{K_j}{V_j^f} = \frac{1}{\theta_j^f} \left\{ \alpha_j^f + (1-\alpha_j^f) \left(\frac{\alpha_j^f (1+\tau_j^l) w}{(1-\alpha_j^f)(1+\tau_j^k) r} \right)^{1-\sigma_j^f} \right\}^{\frac{\sigma_j^f}{1-\sigma_j^f}}, \quad (2)$$

$$l_j = \frac{L_j}{V_j^f} = \frac{1}{\theta_j^f} \left\{ \alpha_j^f \left(\frac{(1-\alpha_j^f)(1+\tau_j^k) r}{\alpha_j^f (1+\tau_j^l) w} \right)^{1-\sigma_j^f} + (1-\alpha_j^f) \right\}^{\frac{\sigma_j^f}{1-\sigma_j^f}}. \quad (3)$$

Here, τ_j^e is an industry output tax rate imposed on the monetary value, τ_j^k is a capital tax rate, τ_j^l is a labor tax rate, r is a nominal rental rate, and w is a nominal wage rate. m_j is the markup ratio expressed as a percentage of unit primary factor cost.

The production technology of the composite energy input and the composite waste disposal service input are also expressed as the CES functions. As a result, an energy input coefficient, e_{ij} , and the waste disposal service input coefficient, ω_{ij}^s , are derived by the cost minimization behavior as follows.

$$e_{ij} = \frac{E_{ij}}{V_j^e} = \frac{1}{\theta_j^e} \left\{ \sum_{k=1}^n \alpha_{kj}^e \left(\frac{\alpha_{ij}^e P_{kj}^e}{\alpha_{kj}^e P_{ij}^e} \right)^{1-\sigma_j^e} \right\}^{\frac{\sigma_j^e}{1-\sigma_j^e}} \text{ for } i=1, \dots, n; j=1, \dots, m+n+p, \quad (4)$$

$$\omega_{ij}^s = \frac{W_{ij}^s}{V_j^w} = \frac{1}{\theta_j^w} \left\{ \sum_{k=1}^p \alpha_{kj}^w \left(\frac{\alpha_{ij}^w (P_k^{ws} + \tau_k^{ws})}{\alpha_{kj}^w (P_i^{ws} + \tau_i^{ws})} \right)^{1-\sigma_j^w} \right\}^{\frac{\sigma_j^w}{1-\sigma_j^w}} \text{ for } i=1, \dots, p; j=1, \dots, m+n+p \quad (5)$$

Here, E_{ij} is the energy input $i=1, \dots, n$ (for example, petroleum, coal, electricity, and gas, etc.) of industry j , θ_j^e is a scale parameter, σ_j^e is the elasticity of substitution among energy source inputs, and α_{ij}^e is the share parameter of each energy input. P_{ij}^e is the price of energy input accounting for the carbon dioxide emission level and the carbon tax. The ordinary input-output model usually treats these energy source input coefficients as fixed. In this model, however, they could be changed in accordance with the variation in their relative prices and imposed tax rates. This will be explained in detail later. For the waste disposal service demand function, W_{ij}^s is a waste disposal service input $i=1, \dots, p$ (for instance, incineration, waste shredding, waste composting, dehydration, reclamation, etc.) of industry j , θ_j^w is a scale parameter, σ_j^w is the elasticity

of substitution among waste disposal service inputs, and α_{kj}^w is the share parameter of each waste disposal service input. τ_i^{ws} stands for the waste disposal tax (or subsidy) rate imposed on each waste disposal service input on physical based unit (such as yen per ton) and is the price of waste disposal service input.

3.1.2 Substitution effect

One of the main purposes in performing this analysis is to clarify the behavior of production sectors with respect to the substitution effect between virgin and recycled material inputs, such as virgin steel and a recovered steel scrap, in the intermediate input technology for any industry¹⁰. For this reason, while keeping b_{ij} constant, let us state the interconnection between virgin material input and waste-recycled input coefficients. First, the intermediate input requirement of any commodity from an industry j , U_{ij} , is expressed as a function of a virgin material input, U'_{ij} , and a waste-recycled input, U''_{ij} , by the following CES function with a scale parameter θ_{ij}^u , the elasticity of substitution ρ_{ij}^z and the share parameter β_{ij}^z .

$$U_{ij} = \theta_{ij}^u \left\{ \beta_{ij}^z (U'_{ij})^{\frac{\rho_{ij}^z-1}{\rho_{ij}^z}} + (1-\beta_{ij}^z)(U''_{ij})^{\frac{\rho_{ij}^z-1}{\rho_{ij}^z}} \right\}^{\frac{\rho_{ij}^z}{\rho_{ij}^z-1}} \text{ for } i=1, \dots, m, j=1, \dots, m+n+p$$

Then, the substitutable intermediate input demands, determined by minimizing the cost of producing a given level of intermediate input, are determined by

$$b'_{ij} = \frac{U'_{ij}}{U_{ij}} = \frac{1}{\theta_{ij}^u} \left\{ \beta_{ij}^z + (1-\beta_{ij}^z) \left(\frac{\beta_{ij}^z (1+\tau_i'') P_i''}{(1-\beta_{ij}^z)(1+\tau_i') P_i'} \right)^{1-\rho_{ij}^z} \right\}^{\frac{\rho_{ij}^z}{1-\rho_{ij}^z}} \text{ and} \tag{6}$$

$$b''_{ij} = \frac{U''_{ij}}{U_{ij}} = \frac{1}{\theta_{ij}^u} \left\{ \beta_{ij}^z \left(\frac{(1-\beta_{ij}^z)(1+\tau_i') P_i'}{\beta_{ij}^z (1+\tau_i'') P_i''} \right)^{1-\rho_{ij}^z} + (1-\beta_{ij}^z) \right\}^{\frac{\rho_{ij}^z}{1-\rho_{ij}^z}} . \tag{7}$$

Here, b'_{ij} is the intermediate input coefficient of virgin material, b''_{ij} is the intermediate input coefficient of recycled material. τ_i' and τ_i'' are the virgin material input tax rate and the recycled material input tax (or subsidy) rate, respectively. P_i' is the price of virgin material (ordinary goods), and P_i'' is the price of recycled material input.

According to the energy input demand, the production sectors also perform the substitution behavior like the intermediate input requirement explained above. Let P_i^{re} and P_i^{te} be the price of primary and thermal recycled energy source input, respectively.

Then, each industry's energy input price accounting for the carbon dioxide emission level and tax, P_{ij}^{re} and P_{ij}^{te} , could be expressed as:

$$\begin{aligned} P_{ij}^{re} &= P_i^{re} + \tau^e \phi_{ij}^{re} \text{ for } i=1, \dots, n; j=1, \dots, m+n+p, \\ P_{ij}^{te} &= P_i^{te} + \tau^e \phi_{ij}^{te} \text{ for } i=1, \dots, n; j=1, \dots, m+n+p, \end{aligned}$$

¹⁰ Virgin and recycled material inputs are perfectly substitutable in Washida's model. Masuda et al. (2000) use the Cobb-Douglas type production function implying that virgin materials and waste materials are substitutable in a symmetric fashion. To avoid the strange behavior against the well observed fact that one can use the latter in place of the former only to a limited extent, an extraneous elasticity value can be set to any proper low level. Furthermore, the optional constraint can be added to set the upper limit of recycled material usage for any industry, i.e. to define the model as a complementary problem. For further details, see Ferris, M. C. and Pang J. S. (1997).

where and ϕ_{ij}' are ϕ'' respectively a Carbon dioxide emission level (in Ton Carbon) per unit primary energy source input and per unit thermal recycled energy source input of industry j . τ^e is a Carbon emission tax levied per unit Ton Carbon. By adopting the minimization behavior, the primary and thermal recycled energy source input coefficients, e_{ij}' and e_{ij}'' , are determined as:

$$e_{ij}' = \frac{E_{ij}'}{E_{ij}} = \frac{1}{\theta_{ij}^e} \left\{ \beta_{ij}^e + (1 - \beta_{ij}^e) \left(\frac{\beta_{ij}^e P_{ij}''^{e}}{(1 - \beta_{ij}^e) P_{ij}^{e}} \right)^{1 - \rho_{ij}^e} \right\}^{\frac{\rho_{ij}^e}{1 - \rho_{ij}^e}}, \tag{8}$$

$$e_{ij}'' = \frac{E_{ij}''}{E_{ij}} = \frac{1}{\theta_{ij}^e} \left\{ \beta_{ij}^e \left(\frac{(1 - \beta_{ij}^e) P_{ij}^{e}}{\beta_{ij}^e P_{ij}''^{e}} \right)^{1 - \rho_{ij}^e} + (1 - \beta_{ij}^e) \right\}^{\frac{\rho_{ij}^e}{1 - \rho_{ij}^e}}. \tag{9}$$

3.1.3 Price system

Due to the homogeneous of degree one property of the CES functions and under the competitive market assumption, each firm exposes to the zero profit condition. According to this assumption, it is beneficial to derive the price system of producers for the purpose of capturing the market clearance conditions later.

Firstly, the price of aggregated other inputs establishes the balance with the price of primary factor input, the composite energy input, and the composite waste disposal service input.

$$P_j^{ex} = P_j^f v_{ej}^f + P_j^e v_{ej}^e + P_j^w v_{ej}^w \tag{10}$$

Next, each price component in equation (10) could also be further formulated using the balance condition as shown in equation (11)-(13):

$$P_j^f = (1 + \tau_j^s)(1 + m_j) \left((1 + \tau_j^r) r k_j + (1 + \tau_j^l) w l_j \right), \tag{11}$$

$$P_j^e = \sum_{i=1}^n P_{ij}^e e_{ij}^e, \tag{12}$$

$$P_j^w = \sum_{i=1}^p (P_i^{ws} + \tau_i^{ws}) \omega_{ij}^s. \tag{13}$$

To account for the substitution effect, each energy input price must again be related to its substitutable primary and thermal recycled energy source input price as:

$$P_{ij}^e = P_{ij}^{e'} e_{ij}' + P_{ij}^{e''} e_{ij}'' \tag{14}$$

The price of composite intermediate input, P_{ij}^m , describing the relationship between the price of a virgin material input, and the price of a recycled material and the composite price of *all* intermediate inputs, , are presented in equation (15).

$$P_{ij}^m = (1 + \tau_i^r) P_i^r b_{ij}^r + (1 + \tau_i^l) P_i^l b_{ij}^l \tag{15}$$

Finally, combining the composite price of *all* intermediate inputs with the price of aggregated other inputs comprises the composite output price, P_j , as follows.

$$P_j = P_j^{ex} b_j^{ex} + \sum_{i=1}^m P_{ij}^m b_{ij}^m \tag{16}$$

3.1.4 The output of goods and services

To explain the structure of the economy's supply side, we need to apply a make matrix

as a tool to convert the activity level of each industry g_j into the output levels of goods and services. We assume that the production levels of primary and secondary products within industries are technologically constrained, and that the market shares of the by-products from the industries are temporally stable. The important point is that there exist no scraps/wastes without the joint- production of primary and secondary products.

This is called the *mixed technology assumption*. Using this concept, we propose the following two matrices¹¹. The first matrix is called the *primary and secondary product -mix (ps) make matrix*:

$$C^{ps} = \begin{bmatrix} c_{1,1}^{ps} & \cdots & c_{1,m+n}^{ps} & \mathbf{0}_{(m+n) \times p} \\ \vdots & \ddots & \vdots & \\ c_{m+n,1}^{ps} & \cdots & c_{m+n,m+n}^{ps} & \\ \mathbf{0}_{p \times (m+n)} & & & \mathbf{I}_{p \times p} \end{bmatrix},$$

where the element $(c_{ij}^{ps})_{i,j=1,\dots,m+n}$ represents the output of goods i per unit activity level of goods, services and energy-related industries j . The elements along the diagonal of a $(p \times p)$ identity matrix represents the output of waste disposal services solely produced by types of waste treatment service industries.

The second one is the *marketable by-products (mb) market shear matrix*:

$$C^{mb} = \begin{bmatrix} c_{1,1}^{mb} & \cdots & c_{1,m+n}^{mb} & c_{1,m+n+1}^{mb} & \cdots & c_{1,m+n+p}^{mb} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ c_{m+n,1}^{mb} & \cdots & c_{m+n,m+n}^{mb} & c_{m+n,m+n+1}^{mb} & \cdots & c_{m+n,m+n+p}^{mb} \\ \mathbf{0}_{p \times (m+n)} & & & & & \mathbf{0}_{p \times p} \end{bmatrix}$$

where the element $(c_{ij}^{mb})_{i,j=1,\dots,m+n}$ represents the market share of by-product i of goods, services and energy-related industries j , and $(c_{i,m+n+j}^{mb})_{i=1,\dots,m+n;j=1,\dots,p}$ represents the market share of by-products or recycled products of waste treatment service j .

This make structure implies that the outputs of the by-products and recycled products depend not only on the goods, services and energy-related industries' activity level but also on that of waste treatment service producing industry, while the output of each waste treatment service depend only upon its corresponding waste treatment service industry's activity level. Hence, the domestic supply level of each product can be determined as follows.

Primary and secondary ordinary goods, $q_i' = \sum_{j=1}^{m+n} c_{ij}^{ps} g_j$ for $i=1,\dots,m$

By-products and recycled goods, $q_i'' = \sum_{j=1}^{m+n+p} c_{ij}^{mb} g_j$ for $i=1,\dots,m$

Primary energy outputs, $q_{m+i}' = \sum_{j=1}^{m+n} c_{m+i,j}^{ps} g_j$ for $i=1,\dots,n$

Thermal recycled energy outputs, $q_{m+i}'' = \sum_{j=1}^{m+n+p} c_{m+i,j}^{mb} g_j$ for $i=1,\dots,n$

¹¹ These two matrices are in fact interrelated through the two-layer input-output structure. Again, see Bunditsakulchai (2006) for the detail of underlying assumptions and methodology. Even though the product mix structure is presented in other models like Masui et al. (2000) and Kawase et al (2003), by-products are not clearly concerned.

Waste disposal service outputs, $q_{m+n+i} = g_{m+n+j(\text{at } j=i)}$ for $i=1, \dots, p$

These complete the main structure of the production side's behavior.

3.2 Representative Households

Now, let us explore the demand side of the model. The production process creates a flow of income to the owners of primary factors that consist of capital and labor as a receipt in the budgets of households and as factor-tax revenues in the budgets of a government. Out of their income, households purchase commodities, energy, and waste treatment services.

Mathematically, the household's net disposable income, Y , can be expressed as

$$Y_h = \left(w\bar{L} + r\bar{K} + \sum_{j=1}^{m+n+p} m_j (wL_j + rK_j) \right) (1 - \tau^y - \tau^s) + bR_g - \sum_{i=1}^{m+n} P_i' I_i^{th} - \sum_{i=1}^{m+n} P_i'' I_i^{rh}. \quad (17)$$

Here, \bar{L} and \bar{K} are labor and capital endowment of consumer, respectively. These are shown in the data set as total wage and salary and total operating surplus deducted by a capital tax. The markup ratio m_j represents the producer's revenue of other missing commodities accrued to the consumer. τ^y and τ^s are a household's income tax rate and a social security tax rate. b is the rate of a direct transfer from the government treated as a fixed proportion of total tax revenue accrued to the government, R_g . I_i^{th} and I_i^{rh} are the exogenously given investments in the private sector for the ordinary commodity and recycled product i , respectively.

To take into account the environmental externalities in the society, we use the concept of damage function. The environmental damage function $D = D(\Omega_h, \Omega_i, \Psi)$ is associated with total amount of landfill consumption for household municipal solid wastes, Ω_h , and industrial wastes, Ω_i , expressed in Ton, and total carbon dioxide emission level, Ψ , expressed in Ton-carbon. The marginal damage functions with respect to each variable are assumed to be positive and increasing — i.e. the first and second partial derivatives are positive. From the model structure, we could not express this function in the explicit form due to the lack of the function that clarifies the relationship between the consumption level and the amount of discharged wastes or pollutants. As a result, the social optimal consumption bundle could not be directly derived from the model simulation process. The best that we can do is carrying out the comparative static to examine how the physical amount of each environment quality in damage function change under policy changes, and then comparing the after shock values with the base-run benchmark levels. Moreover, these externalities are modeled by the additive type in the utility function and do not influence household's marginal utility (the first order condition). Then, this problem could be disregard in our model.

Encountering many policy alternatives, the social planner maximizes *net social surplus* — household consumption utility less the above social environmental damage function. We use our model to test for the proposed tax policy by checking the trade-off between decreasing in the utility level and the environment quality improvement. Note that an integrated approach is necessary for identifying the most efficient policy instruments and for setting those instruments at the right levels especially in a world with multiple externalities like our model.

According to the consumption bundles, a weak separability assumption among

composite goods and services, energy, and waste treatment services is introduced into the following CES utility function¹².

$$\max_{\{C_g, C_e, C_w\}} U = \left\{ \gamma_g C_g^{\frac{\delta-1}{\delta}} + \gamma_e C_e^{\frac{\delta-1}{\delta}} + \gamma_w C_w^{\frac{\delta-1}{\delta}} \right\}^{\frac{\delta}{\delta-1}} - D(\Omega_h, \Omega_i, \Psi); \gamma_g + \gamma_e + \gamma_w = 1,$$

where U is a household's utility level, C_g , C_e and C_w are a composite goods and services consumption, a composite energy consumption and a composite waste disposal service consumption of a household, respectively. γ_g , γ_e and γ_w are share parameters and δ is the elasticity of substitution.

For the case of private markets, individuals ignore the effect of their own activities on the total externality. Namely, individual household consumption choices do not have any effect to the changes in the *aggregated* landfill consumption level and the *aggregated* carbon dioxide emission level. Therefore, the differentiation of damage function with respect to each consumption choice becomes zero.

In this decentralized economy, the utility maximization is performed under household's budget constraint, $Y = P_g C_g + P_e C_e + P_w C_w$, with the goods and services composite price, P_g , energy consumption composite price, P_e , and waste disposal service consumption composite price, P_w . Then, the following composite demands could be achieved.

$$C_s = \frac{\gamma_s P_s^{-\delta} Y}{\gamma_g P_g^{1-\delta} + \gamma_e P_e^{1-\delta} + \gamma_w P_w^{1-\delta}}, \quad (18)$$

which applies for $s = g, e$ and w .

Next, maximizing the utility of consuming good or service i , C_{gi} ,

$$\max_{\{C_{gi}\}} C_g = \left(\sum_{i=1}^m \gamma_{gi} C_{gi}^{\frac{\delta_i-1}{\delta_i}} \right)^{\frac{\delta_i}{\delta_i-1}}; \sum_i \gamma_{gi} = 1,$$

subjected to the budget constraint with goods and services price, P'_i , and consumption tax rate, τ_i^c , i.e. $P_g C_g = \sum_{i=1}^m P'_i (1 + \tau_i^c) C_{gi}$, each commodity's demand is then solved as:

$$C_{gi} = \frac{\gamma_{gi} P_g C_g}{(P'_i (1 + \tau_i^c))^{\delta_i} \left(\sum_{k=1}^m \gamma_{gk} (P'_k (1 + \tau_k^c))^{1-\delta_i} \right)} \text{ for } i=1, \dots, m. \quad (19)$$

Substituting these demands into the above utility function, the composite price of goods and services could be solved as shown in equation (20).

$$P_g = \left(\sum_{i=1}^m \gamma_{gi} (P'_i (1 + \tau_i^c))^{1-\delta_i} \right)^{\frac{1}{1-\delta_i}} \quad (20)$$

As for the utility maximization behavior in the energy consumption and the waste disposal service consumption, the household performs exactly the same behavior as in the case of goods and services consumption. As a result, the optimal energy consump-

¹² Another version of household consumption model is designed to verify the effect of proposed waste disposal taxes under the condition that household waste disposal prices are kept constant. The utility of household in this system is no longer depended on the waste disposal service consumption. See Bunditsakulchai (2006) for further details.

tion demand, C_{ei} , and waste disposal service demand, C_{wi} , is derived as in equation (21) and (22), respectively.

$$C_{ei} = \frac{\gamma_{ei}^{\delta_i} P_e C_e}{(P_i^{re} + \tau^e \phi_i)^{\delta_i} \left(\sum_{k=1}^n \gamma_{ek}^{\delta_i} (P_k^{re} + \tau^e \phi_k)^{1-\delta_i} \right)} \text{ for } i=1, \dots, n \tag{21}$$

$$C_{wi} = \frac{\gamma_{wi}^{\delta_i} P_w C_w}{(P_i^{ws} + \tau_i^{ws})^{\delta_i} \left(\sum_{k=1}^p \gamma_{wk}^{\delta_i} (P_k^{ws} + \tau_k^{ws})^{1-\delta_i} \right)} \text{ for } i=1, \dots, p \tag{22}$$

Here, ϕ_i is a Carbon dioxide emission level per unit energy consumption of household, C_{ei} . The energy consumption composite price, P_e , and the waste disposal service composite price, P_w , could also be achieved in the same manner as¹³

$$P_e = \left(\sum_{i=1}^n \gamma_{ei}^{\delta_i} (P_i^{re} + \tau^e \phi_i)^{1-\delta_i} \right)^{\frac{1}{1-\delta_i}} \tag{23}$$

$$P_w = \left(\sum_{i=1}^p \gamma_{wi}^{\delta_i} (P_i^{ws} + \tau_i^{ws})^{1-\delta_i} \right)^{\frac{1}{1-\delta_i}} \tag{24}$$

As the composite prices are included in each demand function, it may be difficult in comprehending the demand mechanism. For this reason, let us explain again in more detail about the process the consumers use to make their choices. Firstly, assume that consumers take the prices of goods and services, energy and waste disposal services as given. Then, according to equation (20), (23) and (24), the composite prices could be calculated. Given the household's disposable income, each composite commodity's demand could then be calculated. Finally, the demands for each goods and services, energy and waste disposal services are derived from equation (19), (21) and (22), respectively.

3.3 Government and Exogenous Demands

In order to reflect the influence of commodity prices, this model presumes a CES-typed function for an exogenous demand. To capture the effect of proposed environmental policy options, such as carbon tax, land-fill tax (or waste disposal tax), we also make the assumption that there is no need for any waste disposal service demand in the government consumption bundle. As a result, the government uses the collected taxes revenue deducted by the direct transfer to a household and the public investment to consume ordinary commodities and energies as shown in the following disposable income balance, Y_g :

$$Y_g = (1-b)R_g - \sum_{i=1}^{m+n} P_i' I_i'^g - \sum_{i=1}^{m+n} P_i'' I_i''^g \tag{25}$$

$I_i'^g$ and $I_i''^g$ are the exogenously given public investment (or increase in stock demand) for the ordinary commodity and recycled product i , respectively. Regarding the consumption bundles, a weak separability assumption among ordinary goods and energies

¹³ Note that the composite prices in household consumption behavior, P_e , P_e and P_w , are not the same as the composite prices in the production sector's cost minimization behavior, P_e^f , P_e^f and P_w^f .

is presumed. Then, the demands for composite commodities could be derived as follows:

$$\tilde{C}_g = \frac{\lambda^{\zeta} \tilde{P}_g^{-\zeta} Y_g}{\lambda^{\zeta} \tilde{P}_g^{1-\zeta} + (1-\lambda)^{\zeta} \tilde{P}_e^{1-\zeta}} \text{ and } \tilde{C}_e = \frac{(1-\lambda)^{\zeta} \tilde{P}_g^{-\zeta} Y_g}{\lambda^{\zeta} \tilde{P}_g^{1-\zeta} + (1-\lambda)^{\zeta} \tilde{P}_e^{1-\zeta}}, \quad (26)$$

where \tilde{C}_g and \tilde{C}_e are the composite goods and services consumption and the composite energy consumption of government, respectively. \tilde{P}_g and \tilde{P}_e are the corresponding composite prices. λ is the share parameter, and ζ is the elasticity of substitution.

Under the budget constraints, $\tilde{P}_g \tilde{C}_g = \sum_{i=1}^m P_i' \tilde{C}_{gi}$ and $\tilde{P}_e \tilde{C}_e = \sum_{i=1}^n P_i'' \tilde{C}_{ei}$, the goods and services demand, \tilde{C}_{gi} , and the energy consumption of government, \tilde{C}_{ei} , are solved as:

$$\tilde{C}_{gi} = \frac{\lambda_{gi}^{\zeta} \tilde{P}_g \tilde{C}_g}{(P_i')^{\zeta} \left(\sum_{k=1}^m \lambda_{gk}^{\zeta} (P_k')^{1-\zeta} \right)} \text{ and } \tilde{C}_{ei} = \frac{\lambda_{ei}^{\zeta} \tilde{P}_e \tilde{C}_e}{(P_i'')^{\zeta} \left(\sum_{k=1}^n \lambda_{ek}^{\zeta} (P_k'')^{1-\zeta} \right)}. \quad (27)$$

Finally, we could determine the composite price for commodity and energy in term of each commodity's price as:

$$\tilde{P}_g = \left(\sum_{i=1}^m \lambda_{gi}^{\zeta} (P_i')^{1-\zeta} \right)^{\frac{1}{1-\zeta}} \text{ and } \tilde{P}_e = \left(\sum_{i=1}^n \lambda_{ei}^{\zeta} (P_i'')^{1-\zeta} \right)^{\frac{1}{1-\zeta}}. \quad (28)$$

3.4 Rest of the world

To deal with the transaction against the foreign sector, we firstly make the assumptions that any export-import commodity has the same quality as the domestic one, and there is no import and export for waste treatment services. We utilize the function form that show the response from domestic prices and the exchange rate toward the import and export demands. Moreover, the import demand is also affected by *the income effect*, which is in proportion to the corresponding commodity's total domestic output value. Ignoring this income effect could lead to an unrealistic reaction in the case that demands for commodities depend heavily on foreign imports rather than domestically produced ones. Then, under the premise that there is no import and export tariff, we propose the following functions.

$$EX_i' = \omega_i^{\text{ex}} \left(\frac{P_i'}{x} \right)^{\xi_{ex}'} \text{ and } EX_i'' = \omega_i^{\text{ex}} \left(\frac{P_i''}{x} \right)^{\xi_{ex}''} \text{ for } i=1, \dots, m+n \quad (29)$$

$$IM_i' = \omega_i^{\text{im}} \left(\frac{P_i'}{x} \right)^{\xi_{im}'} + \sum_{j=1}^{m+n} (\kappa_{ij}^{\text{ps}}) g_j \text{ and} \quad (30)$$

$$IM_i'' = \omega_i^{\text{im}} \left(\frac{P_i''}{x} \right)^{\xi_{im}''} + \sum_{j=1}^{m+n+p} (\kappa_{ij}^{\text{mb}}) g_j \text{ for } i=1, \dots, m+n$$

EX_i and IM_i are the exported value and the imported value of commodity i . ω_i^{ex} and ω_i^{im} are the scale parameter representing the relative price effect of exported goods and imported goods, respectively. ξ_{ex} is the relative price elasticity in the export function. ξ_{im} is the relative price elasticity in the import function. x is the exchange rate, and κ_i is the

income effect coefficient of imported goods. The single dash superscript (for example, EX_i') distinguishes the ordinary goods from the recycled ones having the double dash superscript (for example, EX_i'').

4 Equilibrium Conditions

We first present private market equilibria — ignoring the effect of each sector’s activity on the environmental externalities — and then show how the Walras’s law could be proved from this model. On the production side, the budget balance of each production sector is obtained by substituting equation (10), (11), (12) and (13) into (16) and then multiplying both sides by the activity level g_j .

$$\begin{aligned}
 P_j g_j &= P_j^{ex} b_j^{ex} g_j + \sum_{i=1}^m P_{ij}^m b_{ij} g_j \\
 &= (1 + \tau_j^s)(1 + m_j) \left((1 + \tau_j^t) r k_j + (1 + \tau_j^w) w k_j \right) g_j \\
 &+ \sum_{i=1}^n P_{ij}^e b_{m+i,j} g_j + \sum_{i=1}^p (P_i^{ws} + \tau_i^{ws}) b_{m+n+i,j} g_j + \sum_{i=1}^m P_{ij}^m b_{ij} g_j
 \end{aligned} \tag{31}$$

where,
$$b_{m+i,j} = \frac{V_j^{ex}}{g_j} \cdot \frac{V_j^e}{V_j^w} \cdot \frac{E_{ij}}{V_j^s} = b_j^{ex} v_{ej}^e e_{ij} \text{ for } i=1, \dots, n$$

$$b_{m+n+i,j} = \frac{V_j^{ex}}{g_j} \cdot \frac{V_j^w}{V_j^s} \cdot \frac{W_{ij}^s}{V_j^w} = b_j^{ex} v_{ej}^w \omega_{ij}^s \text{ for } i=1, \dots, p$$

$$\begin{aligned}
 P_{ij}^e &= P_{ij}^{e'} e_{ij}' + P_{ij}^{e''} e_{ij}'' \\
 P_{ij}^m &= (1 + \tau_i^t) P_i^t b_{ij}' + (1 + \tau_i'') P_i'' b_{ij}''
 \end{aligned}$$

No industry anywhere in the perfect competition world may make above-normal profits. In equilibrium, the total value of sales for any industry exactly covers its cost of production. Were this not the case, industries making losses would cease the operation. Equally, if positive profit were possible, given the constant returns to scale assumption used in this model, industries would make attempt to produce large amounts of output and equilibrium could not prevail.

For the private markets, the household budget balance is presented as follows.

$$\begin{aligned}
 &\left(w\bar{L} + r\bar{K} + \sum_{j=1}^{m+n+p} m_j (wL_j + rK_j) \right) (1 - \tau^y - \tau^s) + bR_g - \sum_{i=1}^{m+n} P_i' I_i^h - \sum_{i=1}^{m+n} P_i'' I_i^h \\
 &= P_g C_g + P_e C_e + P_w C_w \\
 &= \sum_{i=1}^m P_i' (1 + \tau_i^t) C_{gi} + \sum_{i=1}^n (P_i^{e'} + \tau^e \phi_i) C_{ei} + \sum_{i=1}^p (P_i^{ws} + \tau_i^{ws}) C_{wi}
 \end{aligned} \tag{32}$$

For the exogenous demand, its budget balance could be drawn as,

$$(1 - b)R_g - \sum_{i=1}^{m+n} P_i' I_i^s - \sum_{i=1}^{m+n} P_i'' I_i^s = \tilde{P}_g \tilde{C}_g + \tilde{P}_e \tilde{C}_e = \sum_{i=1}^m P_i' \tilde{C}_{gi} + \sum_{i=1}^n P_i^{e''} \tilde{C}_{ei}. \tag{33}$$

To close the model with respect to the trade balance in the external-sector transactions, credits must equal debits in the external account, i.e. exports of commodities (received from abroad) must equal imports (paid abroad).

$$\sum_{i=1}^{m+n} P_i' EX_i' + \sum_{i=1}^{m+n} P_i'' EX_i'' = \sum_{i=1}^{m+n} P_i' IM_i' + \sum_{i=1}^{m+n} P_i'' IM_i''. \tag{34}$$

The equilibrium condition according to the commodity balance states that demands must equals supplies for all commodities and factors. Market demands for goods include the household demand, the production sector intermediate input demand, and the government demands, along with the export demand for the foreigners. Market supplies of commodities reflect total production, together with the import demand component in the final demand. Market demands for factors reflect industry uses in production; factor supplies reflect the endowments of the factor owners.

Mathematically, let us define the excess demand function for primary factor — labor, d_l , and capital, d_k — as:

$$d_l = \sum_{j=1}^{m+n+p} l_j v_{ej}' b_{0j} g_j - \bar{L}, \tag{35}$$

$$d_k = \sum_{j=1}^{m+n+p} k_j v_{ej}' b_{0j} g_j - \bar{K}. \tag{36}$$

The ordinary goods and recycled goods excess demand need to be separately treated as the different functions as shown in the equation (37) and (38).

$$d_{gi}' = \sum_{j=1}^{m+n+p} b_{ij}' b_{ij} g_j + C_{gi} + \tilde{C}_{gi} + I_i^h + I_i^g + EX_i' - \left(\sum_{j=1}^{m+n} c_{ij}^{ps} g_j + IM_i' \right) \text{ for } i=1, \dots, m \tag{37}$$

$$d_{gi}'' = \sum_{j=1}^{m+n+p} b_{ij}'' b_{ij} g_j + I_i^{''h} + I_i^{''g} + EX_i'' - \left(\sum_{j=1}^{m+n+p} c_{ij}^{mb} g_j + IM_i'' \right) \text{ for } i=1, \dots, m \tag{38}$$

Like the consumption goods, the energy consumptions could also be drawn from both primary and thermal recycled sources. Therefore, we adopt the following two excess demand functions.

$$d_{ei}' = \sum_{j=1}^{m+n+p} e_{ij}' b_{m+i,j} g_j + C_{ei} + \tilde{C}_{ei} + I_{m+i}^h + I_{m+i}^g + EX_{m+i}' - \left(\sum_{j=1}^{m+n} c_{m+i,j}^{ps} g_j + IM_{m+i}' \right) \text{ for } i=1, \dots, n \tag{39}$$

$$d_{ei}'' = \sum_{j=1}^{m+n+p} e_{ij}'' b_{m+i,j} g_j + I_{m+i}^{''h} + I_{m+i}^{''g} + EX_{m+i}'' - \left(\sum_{j=1}^{m+n+p} c_{m+i,j}^{mb} g_j + IM_{m+i}'' \right) \text{ for } i=1, \dots, n \tag{40}$$

As the waste disposal service could not be recovered, it has only one excess demand.

$$d_{wi} = \sum_{j=1}^{m+n+p} b_{m+n+i,j} g_j + C_{wi} - g_{m+n+j} \text{ (at } j=i) \text{ for } i=1, \dots, p \tag{41}$$

Finally, we define the government excess proceeds function (the budget imbalance), D_g , in correspondence with the taxes revenue, as follows.

$$\begin{aligned} D_g = & (\tau^v + \tau^s) \left(w\bar{L} + r\bar{K} + \sum_{j=1}^{m+n+p} m_j (wL_j + rK_j) \right) \\ & + \sum_{i=1}^m P_i' \tau_i^c C_{gi} + \sum_{i=1}^n \tau_i^c \phi_i C_{ei} + \sum_{i=1}^p \tau_i^{ws} C_{wi} \\ & + \sum_{j=1}^{m+n+p} \tau_j^l w l_j g_j + \tau_j^r r k_j g_j + \tau_j^e (1+m_j) \left((1+\tau_j^l) w l_j + (1+\tau_j^r) r k_j \right) g_j \\ & + \tau^e \sum_{j=1}^{m+n+p} \left(\sum_{i=1}^n (\phi_{ij}' e_{ij}' b_{m+i,j} + \phi_{ij}'' e_{ij}'' b_{m+i,j}) \right) g_j + \sum_{j=1}^{m+n+p} \left(\sum_{i=1}^p \tau_i^{ws} b_{m+n+i,j} \right) g_j \end{aligned} \tag{42}$$

$$+ \sum_{j=1}^{m+n+p} \left(\sum_{i=1}^m (\tau_i' P_i' b_{ij} + \tau_i'' P_i'' b_{ij}'') b_{ij} \right) g_j - R_g$$

Under the above budget balance constraints together with the excess demand functions, the Walras's law could be established. First, assume that the exchange rate is given and all the budget balance constraints are satisfied. Then, the summation of all excess demand *values* must equal to zero, i.e.

$$wd_l + rd_k + \sum_{i=1}^m P_i' d_{gi}' + \sum_{i=1}^m P_i'' d_{gi}'' + \sum_{i=1}^n P_i^{re} d_{ei}' + \sum_{i=1}^n P_i^{re} d_{ei}'' + \sum_{i=1}^p P_i^{ws} d_{wi} + D_g = 0. \quad (43)$$

This model has total of $2m+2n+p+4$ unknown variables, i.e. m ordinary goods prices P_i' , m recycled products prices P_i'' , n primary energy source input prices P_i^{re} , n thermal recycled energy source input prices P_i^{re} , p waste disposal service prices P_i^{ws} , 2 primary factors prices w and r , total government's income R_g , and the exchange rate x . This equals to the total number of equation (35)-(42) plus the equilibrium trade balance condition (34).

5 Micro-consistent Data for Equilibrium Analysis

We describe here the economic accounts appropriate for computable general equilibrium analysis and present a micro-consistent, benchmark data set. The economic accounts provide an explicit and rigorous data framework that focuses on the interactions of economic agents. In the collection and refinement of the numerical data base for this study, the accounts identified variables for which data were required and indicated desirable levels of aggregation.

5.1 Commodity, industry and waste classifications

The data set on which the accounts are based provides statistical information used in three distinct phases of the study: (1) in calibration of structural parameters of the CGE model, (2) in testing the logical consistency of the model, and most importantly, (3) in counterfactual policy experiments.

Three objectives were considered in the selection of data accounts. First, the accounts must explicitly identify flows of products, factors, and income; second, the accounts must correspond to basic variables of the general equilibrium model; third, the number of accounts should be as small as possible without relinquishing the first two objectives.

The following six 1995 Japanese input-output tables estimated by Kagawa et al. (2003) representing economy-wide transaction were chosen: (1) Input-output technological table (X), (2) Input-output product mixed table (V), (3) Waste Input-output (WIO) table, (4) Physical unit input-output table, (5) By-products and scraps input-output table, and (6) Environmental emission coefficient table (See also Ministry of the Environmental of Japan, 2003b; Ministry of the Health and Welfare of Japan, 1995).

These six tables are adjusted and rearranged with regard to the industrial types and their behaviors of waste generation and waste recycling. The table 1 shows the indus-

Table 1: Commodity (Industry) classification

No.	Commodity (Industry) Sectors (1-21)	No.	Commodity (Industry) Sectors (22-42)
1.	Agriculture	22.	Automobile
2.	Mining	23.	Other transportation equipment
3.	Food and tobacco products	24.	Precision instrument
4.	Apparel and textile products	25.	Other manufacturing
5.	Lumber and wood products	26.	Construction
6.	Furniture and fixtures	27.	Wholesale and retail
7.	Pulp, paper and paper products	28.	Financial service and insurance
8.	Printing and publishing	29.	Real estate
9.	Chemical and allied products	30.	Transportation service
10.	Plastic products	31.	Communication and broadcasting
11.	Rubber products	32.	Public administration
12.	Leather and leather products	33.	Education and research
13.	Stone, clay and glass products	34.	Medical service and social insurance
14.	Pig iron and steel products	35.	Other public service
15.	Nonferrous metal products	36.	Service for business
16.	Metal products	37.	Service for person
17.	Industrial machinery and equipment	38.	Others
18.	Office machines and machinery for service industry	39.	Water supply
19.	Household electric appliance	40.	Gas and heat supply
20.	Electric and communication equipment	41.	Petroleum and coal products
21.	Heavy electrical equipment and other electrical devices	42.	Electricity supply

Table 2: Waste disposal service industry classifications

No.	Waste disposal service industry (1-6)
1.	Incineration
2.	Dehydration
3.	Shredding
4.	Waste-composting
5.	Land-filling (Reclamation)
6.	Other treatments

trial classification with 42 sectors roughly separated into 2 large groups as 39 ordinary commodity sectors and 3 energy related sectors (G-industries).

Waste treatment service industries (W-industry) are classified into 6 sectors as shown in Table 2. Each sector has 4 major intermediate inputs for its waste disposal activities, i.e. electricity, petroleum products, chemical products and transportation service, which represents the different waste treatment technology. There are 20 types of industrial and household wastes in this model (Table 3). The share of waste disposed of by the waste treatment technology is represented by the non-negative rectangular al-

Table 3: Industrial and household waste classifications

No.	Industrial waste (1-20)
1.	Incineration ash
2.	Sludge
3.	Waste Oil
4.	Acid waste fluid
5.	Alkaline waste fluid
6.	Waste plastics
7.	Waste papers
8.	Wood chips
9.	Waste fiber
10.	Waste residuals of animals and plants
11.	Waste rubber
12.	Waste metal
13.	Waste glass and ceramics
14.	Slag
15.	Construction wastes
16.	General waste particles
17.	Office machines and machinery for service industry
18.	Infectious medical wastes
19.	Cinders
20.	Others

location matrix $S_1 = (s_{ik})_{i=1,\dots,6; k=1,\dots,20}$ and $S_2 = (s_{ik})_{i=1,\dots,6; k=1,\dots,20}$ for industrial and household wastes, respectively. See Kagawa et al. (2003) for further details about the allocation matrix used in this research.

5.2 Configuration of elasticity parameters

Elasticity of substitution is one of the most influential parameters in this model, because a lot of parameters and coefficients depend on its value. Consequently, the configuration of elasticity parameters has a much impact on the performance of an entire model. At the same time, the value of this substitution elasticity fluctuates largely according to difference in the estimation methods and the data bases. Moreover, it is difficult to catch the tendency of these parameters from previous literatures. As a result, in performing the simulations, we adjust these parameters little at a time by taking notice of the feedback from the model and finally we come up with a suitable configuration of elasticity parameters that make a good response of the model as shown in Table 4¹⁴. Additionally, we also assume that common substitution elasticity applies to all the industries, but different values apply to different levels of production technology. Note that the substitution elasticity in the household consumption functions usually has a high value as compared to that in the production functions. The values of substitution elasticity in the exogenous demands' consumption functions are suppressed at the low level in order to keep the behavior close to the fixed coefficient type.

Table 4: Configuration of elasticity parameters

<i>Definition</i>	<i>Symbol</i>	<i>Value</i>
Elasticity of substitution in the aggregated other input function	σ^{xx}	0.5
Elasticity of substitution between the primary factor (labor and capital)	σ^f	0.6
Elasticity of substitution in the energy input function	σ^e	0.4
Elasticity of substitution in the waste disposal service input function	σ^w	0.4
Elasticity of substitution between virgin and recycled material input	ρ_{ij}^v	0.7
Elasticity of substitution between natural and thermal recycled energy input	ρ_{ij}^e	0.7
Elasticity of substitution in the household main utility function	δ	0.6
Elasticity of substitution in the household goods and services consumption	δ_g	0.7
Elasticity of substitution in the household energy consumption	δ_e	0.4
Elasticity of substitution in the household waste disposal service consumption	δ_w	0.4
Elasticity of substitution between the exogenous aggregated demands	ζ	0.3
Elasticity of substitution in the exogenous demands' goods and services consumption	ζ_g	0.3
Elasticity of substitution in the exogenous demands' energy consumption	ζ_e	0.3
Relative price elasticity in the export function	$\xi_{ex}^', \xi_{ex}^{''}$	-0.25
Relative price elasticity in the import function	$\xi_{im}^', \xi_{im}^{''}$	0.25

With regard to the relative price elasticity in the export and import demand functions, Washida (2004) states that it has a propensity to decrease gradually since 1970s and this value fell down to about 0.2 in 1993 and moved up to about 0.4 in 1997 according to the Japanese white paper on international trade. Referring to this, we set the absolute value of the relative price elasticity to be 0.25 in this model.

6 The Policy Implication and Major Findings

6.1 Model simulation scenario

A scenario is a specification of exogenous changes in selected variables of the model. To conduct an experiment in the CGE model, a scenario is introduced into the benchmark economy. The scenario represents a shock to the initial comparative static equilibrium. All other exogenous variables besides those indicated in the scenario are held constant. The equations of the model are then solved to obtain new equilibrium values for each of the endogenous variables. The difference between the initial and derived values of these variables is interpreted as the effect of the scenario.

The experiment is conducted to assess the economic and environmental effects of

¹⁴ it is a standard practice of CGE modeling that extraneous elasticity values are vastly specified on the case-by-case basis depending on estimation method and available data, as noted in Shoven, J. and Whalley, J. (1992, pp. 118-123) and Washida, T. (2004, pp. 216-217). No econometric estimation by the historical data is done here. The values are drawn from Washida (2004, Table 7.10 pp. 217) as a guidance for the adjustment.

changes in waste disposal tax policy. This short-run tax policy changes is described by levying a *1000 yen per ton* of tax (effective rate of tax: 1995 price) to the disposal service of industrial wastes and the household solid wastes by the reclamation (land-filling) method and keeping all other taxes constant.

The experiment is also designed for testing the possibility of alleviating the welfare lost as the result of imposing a waste disposal tax under the government *revenue neutralization* scheme by keeping the total revenue from all taxes and saving of government constant. The tax revenue from the waste disposal taxes can be used to decrease either the income tax rate or the capital tax rate.

Results of the experiment at a national level are reported in Table 5.

If 1000 yen per ton landfill tax is put into execution throughout Japan, the restraint effects to reduce the landfill consumption of industrial wastes and household wastes are estimated to be about 57.0 (-20.79%) and 1.54 (-19.92%) million tons, respectively. It could be said from these figures that these effects are significant. Moreover, we should take the 8.3 (0.614%) billion yen of recycling facilitatory effect into consideration. According to the carbon-dioxide emission reduction impact, although it is seemed to be small, total carbon-dioxide emission is reduced by imposing 1000 yen per ton of landfill tax. This could be said to be the *double-dividend* advantage of the waste disposal tax¹⁵.

Next let us explain the influence of imposing 1000 yen per ton of landfill tax from the welfare facet. In this model, total amount of labor and capital are completely employed by the production sectors. This makes the nominal net domestic product determined only by the wage rate w and rental rate r . According to the counterfactual policy experiment, the nominal net domestic product is decreased by 0.007% (19.2 bil-

Table 5: Overall effects of the proposed landfill tax (1000 yen/ton)

Variables	Base-run Value	After-shock Value	Percentage change
EV for goods and services (Billion yen)	0	-13.1	-0.005%
Total industrial landfill consumption (Million Tons)	274.2	217.2 (-57.0)	-20.79%
Total household landfill consumption (Million Tons)	7.71	6.17 (-1.54)	-19.92%
Total recycled products value (Billion yen)	1348.2	1356.5 (8.3)	0.614%
Total carbon-dioxide emission (Million Ton-carbon)	313.56	312.98 (-0.57)	-0.183%
Gross National Product (GNP) value (Trillion yen)	929.79	929.59 (-0.20)	-0.022%

¹⁵ Note that the definition of double-dividend here is different from what defined in Goulder (1994) and Kawase et al. (2003). Since using tax revenue from the waste disposal taxes to decrease either the income tax rate or the capital tax rate is similar to those in Kawase et al. (2003), the double-dividend advantage of the waste disposal tax in the traditional fashion is also verified here.

lion yen). This figure somehow indicates the lowering in welfare level. Nonetheless, in consideration of the change in relative prices, we are supposed to refer to the equivalent variation (EV) of income. The accurate decrease in consumer's welfare is therefore estimated as -0.005% (13.1 billion yen).

By keeping the total revenue from all taxes R_g constant, the welfare lost effect can be drastically improved by this government revenue neutralization scheme. The underlying reason is that the tax revenue from the waste disposal taxes can be used to decrease the income or capital tax rate. Therefore, the welfare loss is relieved due to the increment in purchasing power of consumers.

We should also note that the capital uses are more sensitive to the waste disposal tax than the labor uses. This implies that the economic sectors tend to shift toward the capital-intensive technology as a result of the elevated rate of waste disposal cost. The after-shock exchange rate is 0.0247% higher than the base-run value. Hence, the import demands go up while the export demands drop down, bringing about a small deficit in the foreign current account.

At the industrial level, the landfill tax has the comparatively greater effect on the energy and service sector than on the relatively waste-producing sectors such as pulp, paper and paper products or pig iron and steel products industry (manufacturing sector) with respect to the percentage changes in the commodity prices, total industrial outputs and household consumptions.

Incineration and energy producing sectors (Petroleum, Coal, Gas and Electricity) could noticeably bring about the reduction in carbon dioxide emission, while agriculture and mining industry generated more air pollution as a result of imposing the landfill taxes (see Figure 3).

Figure 4 explains that the recycling-oriented sectors like apparel and textile products, pulp, paper and paper products, and chemical and allied products industries are in

Figure 3: The reduction in carbon dioxide emission as a result of imposing the landfill tax (%)

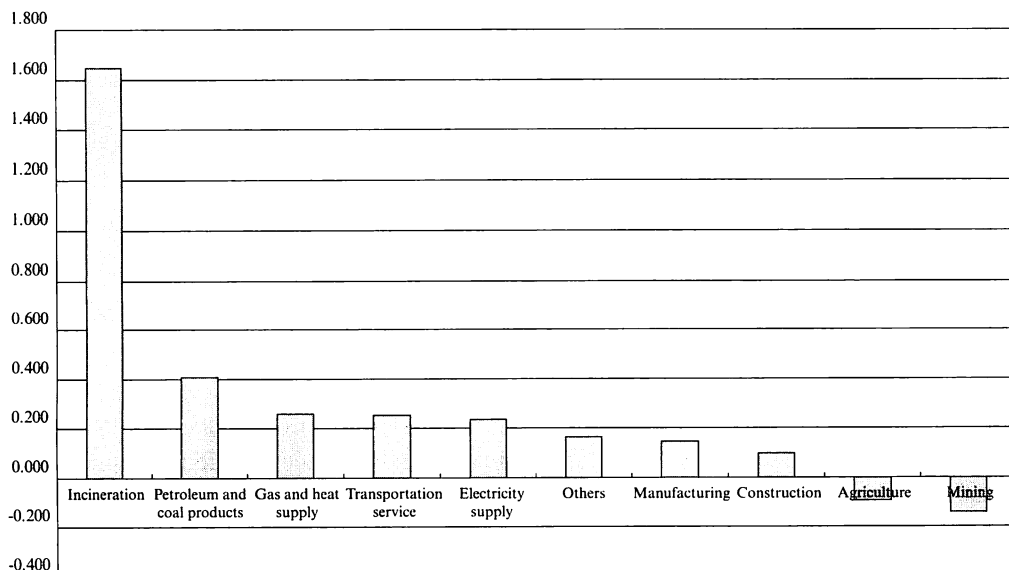
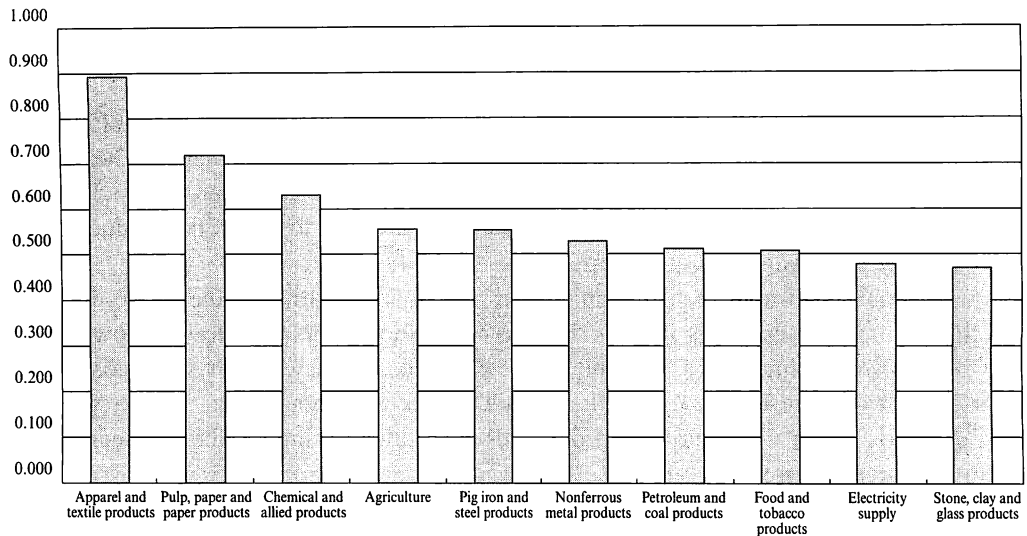


Figure 4: The increment in recycled product value by sectors (%)

the top rank of declination in recycled products due to the affirmative increasing in the prices of recycling waste plastics, construction wastes and waste glass and ceramics.

The thermal recycled products especially petroleum and coal products play a magnificent role in controlling the carbon-dioxide emission through the relatively cheaper in their prices with respect to those of ordinary energy sources.

6.2 Limitations, extensions, and discussion

Some authors have argued that a Pigovian tax on waste disposal is infeasible because of the potential for illicit dumping or burning and the monitoring or enforcement problems (Dinan, 1993; Fullerton and Kinnaman, 1995; Eskeland and Devarajan, 1996; Palmer and Walls, 1997). However, in general equilibrium, only the relative prices of waste disposal services matter, and the waste disposal tax can therefore be set equal to zero as long as taxes on all other relevant activities are adjusted so as to induce desired relative prices.

To avoid the possibility of illegal dumping, the free collection of garbage is quite sensible with the subsidy on legal disposal close to the direct cost of garbage collection. However, taxes on relevant private consumption are required to restore the proper relative prices in general equilibrium. This consumption tax rate should reflect the externality such as aesthetic and health costs on those who live near the landfill area and the possible externality from illicit dumping or burning. This is called a deposit-refund system or a two-part instrument. In general case, the Pigovian tax would raise the relative price of polluting choice (such as reclamation) and induce producers to substitute for the other input (such as incineration or shredding) through *the substitution effect*. It would also raise the price of output and thus reduce the equilibrium output quantity through *the output effect*. The two-part instrument uses the subsidy to achieve the desired substitution effect and uses the output tax to fix the output effect. This is the intuition underlying the two-part instrument.

The welfare lost effect in our model can be further improved by the government revenue neutralization scheme. By keeping the total revenue from all taxes and saving R_g constant. Having industrial waste taxes be national taxes used for environmental restoration, the problem is arisen in the light of how the revenue from these taxes can be used.

Other than using the tax revenue from the waste disposal taxes to decrease the income or capital tax rate in relation to double taxation, municipalities have other choices such as to raise waste management funds, to put the collected revenue into a fund for waste reduction and other purposes, and to use collected fees to fund measures for promoting recycling.

For example, Mie Prefecture levies a tax of 1,000 yen per ton (the same amount as levied in this paper) on businesses that annually generate 1,000 tons or more of industrial waste that undergoes intermediate processing and final disposal in the prefecture. This covers about 60% of industrial waste and the fee does not exceed the cost of transport outside the prefecture. Uses for the revenues include subsidizing the cost of developing technologies for decreasing business waste generation, infrastructure preparation around final disposal sites with public-sector involvement, and beefed-up monitoring of illegal dumping. Taxing industrial waste is an environmental good because it encourages, for example, waste reduction and recycling. There are also expectations that such taxes will discourage bringing waste from other prefectures, strengthen monitoring of illegal dumping, and provide funds for environmental restoration.

Three observations can be made on this trend.

1. The Law on Legislation for Government Decentralization, which became effective in April 2000, made it easy for municipalities to introduce non-statutory independent taxes (non-statutory general and special purpose taxes).
2. Local governments are beginning to perceive the importance of economic instruments in environmental policy because they can see the limitations to using existing regulatory instruments, as in the increases in carbon dioxide and waste emission.
3. The financial situations of municipalities are deteriorating. Local tax revenues are slumping badly due to the recession, making it urgent to secure stable revenue sources.

Although industrial waste taxes provide little revenue, their greatest significance is that they are a form of taxation which substitutes for income and corporate taxes, and which reduces waste generation and the environmental burden. This created an opening for environmental taxes, which are used for environmental conservation. The exclusive use of administrative guidance and regulations until now did not offer enough incentive, but the exemption from this tax for businesses generating under 1,000 tons offers them an incentive to lower their tax liability by generating less waste. Up to May 2005, 23 prefectures have already introduced industrial waste taxes.

7 Conclusion

The present paper contributes to developing the CGE-based model designed for the environmental policy appraisal program. Framework focuses on the entire life-cycle of each product and waste generated from virtually any source in the economy. The proposed model demonstrates how industrial, household, and waste disposal service (or recycling) sectors are connected each other. In addition, it shows how wastes are generated from these sectors. Calibrated with the 1995 Japanese input-output data set, the proposed model is applied to evaluate the environmental and economic consequences of the landfill tax by running the simulation in which the benchmark equilibrium of the CGE model is perturbed by the imposed tax policy.

Some of the results are specified here. By imposing 1000 yen per ton of landfill tax to the whole economy, the industrial and household wastes are estimated to be reduced by about 57.0 (-20.79%) and 1.54 (-19.92%) million tons, respectively. Accompanied by the carbon emission suppression about 574.3 thousand tons-Carbon, the proposed tax policy could manifestly bring about the total environmental burdens restrain effect under the relatively slight declination in the welfare level.

This model has some points to be further improved. First, the paper does not consider the possibility of illegal waste disposal. However, this could be easily done by setting an appropriate two-part instrument scheme to the model, for example by levying the output taxes on the dirty goods and followed by subsidizing for clean technology used in production, or for recycling the final good. The point is also to avoid the enforceability or measurement problems of a tax on pollution by applying the tax to observable market transactions such as the purchase of an output by consumer and simultaneously to subsidize other market transactions such as the purchase of clean inputs by the polluting firm.

Second, in many recycling markets, the government orders the producers to recycle their products. Thus, recycling is not voluntary. The government often specifies the recycling rate of a weight base. Unfortunately, under the strong assumption that the technology of each firm remains constant in this static model make us unable to handle with this aspect. Some adaptation should be implemented to make this model become more realistic under the economic systems with goods and bads.

Third, considering the recycling promotion aspect, the thermal recycling is much more feasible to implement than the recycled raw materials because of the inefficiency of material recycling method. Promoting thermal recycling also contribute to the reduction in carbon-dioxide emission resulting from fossil fuel refinery process.

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