A GENERAL EQUILIBRIUM ANALYSIS OF THE WASTE-ECONOMIC SYSTEM - A CGE MODELING APPROACH -

by Yuzuru MIYATA**

1. Introduction

It has recently been a very important issue to examine the interaction between environment and economic activities. Apart from specific researches on environment relating to industrial activities, inhabitants, or transportation, however, empirical studies on a national or regional macro-environment/economic system have stayed at initial stages, resulting in the insufficiency of systematizing the environment/economic interaction. The main reason of this matter may be attributed to a significant complexity of environment/economic system, and a need for tremendous works to collect and arrange data on the system. Considering these matters, this article focuses on waste in Hokkaido, Japan, as an environmental pollution factor, then construct a computable general equilibrium (CGE) model[1),2)] in order to analyze the interaction between environment and the economy of Hokkaido. Our analysis aims to evaluate the effects of charging household waste discharge, technical progress in waste treatment activities, and promotion of recycling etc. on Hokkaido's economy.

2. Structure of the Model

The model under the study is linked to the following assumptions.

①Economic agents are; aggregate household in Hokkaido, industries (primary, secondary, and tertiary), the government, industrial waste self-treatment activities (abbreviated to S-activities), contract/public waste treatment activity (abbreviated to C/P-activity), and the external sector (rest of the world other than Hokkaido).

②S-activity originally implies a waste treatment activity equipped in a firm. In the study, S-activity is modeled as an independent and aggregate activity, and is classified into three types. That is, primary S-activity which treats waste only generated by primary industry, then secondary and tertiary S-activites are defined similarly.

C/P-activity is composed of specific private activites treating wastes, and a sector of the government that disposes of waste. These activities and the sector are modeled as an aggregate activity.

③Nine markets are considered. They are three commodity markets, three waste self-treatment markets, one contract/public waste treatment market, and two factor (labor and capital) markets.

④Commodity, labor and capital markets are perfectly competitive, and the real economic world is in long-run equilibrium.

⑤The benchmark year is 1985.

Under these assumptions, the structure of the model is described as follows.

(1)Industries

Industries employ intermediate goods, labor and capital minimizing production costs, and discharge industrial waste while they produce commodities. The amount of waste discharged by each industry is assumed to be proportional to its output. This implies that the marginal waste discharge of each industry is constant.

Almost of waste is treated by the S-activities, but a part of waste is disposed of by the C/P-activity. These treatment services are inputted to industries like interme-

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**Member of JSCE, Ph.D., Department of Socio-economic Planning, Toyohashi University of Technology
(Tempaku, Toyohashi, 441, Aichi, Japan, TEL 0532-47-0111, FAX 0532-48-8565)

diate goods. Labor and capital incomes yielded in production process are distributed to households.

The technology of industries is divided into two parts. Leontief technology is adopted to inputs of intermediate goods, value added, and waste treatment services. Cobb-Douglas technology is employed in producing value added with labor and capital inputs. The behavior of industries may be described as follows:

$$\underset{(x1j,\,x2j,\,x3j,\,L1j,\,K1j,\,WTj,\,WT2j)}{\text{Min}} \sum_{i=1}^{3} p_i \cdot x_{ij} + (1+tp_{1j})(w \cdot L_{1j} + r \cdot K_{1j}) + q_j WT_j + q_4 WT2_j \qquad (j=1,2,3) \qquad (1)$$

$$\text{s.t.}\quad X_j = \text{Min}\left\{ \frac{1}{a^1_{0j}} f_{1j}(L_{1j},K_{1j}), \frac{x_{1j}}{a^1_{1j}}, \cdots, \frac{x_{3j}}{a^1_{3j}}, \frac{WT_j}{RWT_j \cdot RWG_j}, \frac{WT2_j}{RWT2_j \cdot RWG_j} \right\} \quad (j=1,2,3) \quad (2)$$

$$f_{1j}(L_{1j},K_{1j}) \equiv A_{1j} L_{1j}^{\alpha_{1j}} K_{1j}^{(1-\alpha_{1j})} \qquad (j=1,2,3) \qquad (3)$$

where p_i:price of industry i product, x_{ij}:intermediate input from industry i to j, tp_{1j}:net indirect tax rate imposed on industry i commodity (i.e. indirect tax rate minus subsidy rate), w:wage rate, r:capital return rate, L_{1j}:labor input of industry j, K_{1j}: capital input of industry j, q_j:price of self-treatment service j, WT_j:the amount of wastes of industry j treated by S-activity, q_4:price of contract/public treatment service, $WT2_j$:the amount of wastes of industry j treated by C/P-activity, X_j:output of industry j, a^1_{0j}:value added rate in industry j, a^1_{ij}:input coefficient, RWT_j:self-treatment rate in industry j, $RWT2_j$:contract/public treatment rate in industry j, RWG_j: marginal waste discharge of industry j (see equation (5)), A_{1j} and α_{1j}:technical parameters in industry j.

It should be noted here that the measurement unit of labor and capital is defined as that it yields one million yen service in the benchmark year. Hence the figures of labor and capital do not coinside with values in standard physical measurements.

Taking the Leontief technology in industrial intermediate and waste treatment service inputs into acount, we obtain the following conditional labor and capital demands.

$$LD_{1j} = \left(\frac{(1-\alpha_{1j})r}{\alpha_{1j} \cdot w}\right)^{\alpha_{1j}} \frac{a_{0j}X_j}{A_{1j}}, \quad KD_{1j} = \left(\frac{\alpha_{1j} \cdot w}{(1-\alpha_{1j})r}\right)^{(1-\alpha_{1j})} \frac{a_{0j}X_j}{A_{1j}} \qquad (j=1,2,3) \qquad (4)$$

Further, industrial waste discharge WG_j, self-treated waste WT_j, and contract/public treated waste $WT2_j$ are derived as follows:

$$WG_j = RWG_j \cdot X_j, \quad WT_j = RWT_j \cdot WG_j, \quad WT2_j = RWT2_j \cdot WG_j \qquad (j=1,2,3) \qquad (5)$$

Finally, due to the assumption of long-run equilibrium in the perfect competition, we obtain the zero profit condition for industries.

$$p_j \cdot X_j - \sum_{i=1}^{3} p_i \cdot a^1_{ij} X_j - (1+tp_{1j})\{w \cdot LD_{1j} + r \cdot KD_{1j}\} - q_j WT_j - q_4 WT2_j = 0 \qquad (j=1,2,3) \qquad (6)$$

(2)Households

Households are assumed to be homogeneous and to have a CES utility function of composite good and leisure. Households choose a combination of a composite and leisure so as to maximaize their utility function under a budget constraint. Then a composite consumption is divided into three parts, that is, consumptions of primary, secondary and tertiary products.

Wage income obtained from supply of entire labor endowment, post-depreciation capital income, current transfers from the government, and factor income and other current transfers from the external sector constitute the household "full income". Some portion of household wage and capital incomes is transfered to the external sector.

Direct taxes and savings are subtracted from the household full income. Then households allocate their disposable income on consumption and leisure. It is assumed that household social security contributions are regarded as direct taxes, for simplicity. Then household behavior may be expressed as follows:

$$\max_{C,F} \{(1-\beta)^{1/\nu} C^{(\nu-1)/\nu} + \beta^{1/\nu} F^{(\nu-1)/\nu}\}^{\nu/(\nu-1)} \qquad (7)$$

$$\text{s.t.}\ \ p \cdot C + (1-ty)(1-l_o)w \cdot F = (1-ty)FI - SH \qquad (8)$$

$$FI = (1-l_o)w \cdot E + LI + (1-k_o)(1-k_r)r \cdot KS + KI + TrGH + TrOH \qquad (9)$$

$$SH = s(1-ty)FI \qquad (10)$$

where **β**:share parameter, **ν**:elasticity of substitution, **C**:composite consumption, **F**:leisure, p:price of composite good, ty:direct tax rate, **FI**:full income (full wage income subtracted by wage income transfers to the external sector + capital income subtracted by property income transfers to the external sector and capital depreciation + current transfers from the government + current transfers from the external sector), **E**:household initial labor endowment (=three times labor supply in the benchmark year. This is interpreted as that working time in a day is 8 hours, hence it is 1/3 of 24 hours.), **l_o**:rate of wage income transfers to the external sector, **LI**:wage income transfers from the external sector (exogenously given), **k_o**:rate of property income transfers to the external sector, **k_r**:capital depreciation rate, **KI**:property income transfered from the external sector (exogenously given), **KS**:household initial capital stock endowment, **SH**:household savings, **s**:rate of savings.

The solution of the utility maximization problem gives demands for the composite good and leisure.

$$C = \frac{(1-\beta)\{(1-ty)FI-SH\}}{p^{\nu} \cdot \Omega}, \quad F = \frac{\beta\{(1-ty)FI-SH\}}{((1-ty)(1-l_o)w)^{\nu} \cdot \Omega}, \quad LS = E - F \qquad (11)$$

$$\Omega = (1-\beta)p^{(1-\nu)} + \beta((1-ty)(1-l_o)w)^{(1-\nu)} \qquad (12)$$

where **LS**:household labor supply.

The comosite good is further divided into sectoral commodities under maximization of Cobb-Douglas sub-utiliy functions, given the income and leisure demand.

$$\max_{C_j} \prod_{j=1}^{3} C_j^{\alpha_j} \quad (\sum_{j=1}^{3} \alpha_j = 1) \qquad \text{s.t.}\ \sum_{j=1}^{3} p_j \cdot C_j = (1-ty)Y - SH \qquad (13)$$

where **C_j**:commodity j, **p_j**:price of commodity j,
Y:household income $(=(1-l_o)w \cdot LS + LI + (1-k_o)(1-k_r)r \cdot KS + KI + TrGH + TrOH)$

Hence sectoral consumption functions are obtained as follows:

$$C_j = \frac{\alpha_j}{p_j}((1-ty)Y - SH) \qquad (j=1,2,3) \qquad (14)$$

The price of composite good can be denoted by using commodity prices as follows:

$$p = \prod_{j=1}^{3} \left(\frac{p_j}{\alpha_j}\right)^{\alpha_j} \qquad (15)$$

(3)Waste Discharge

Industries and households discharge wastes. The amount of industrial waste is assumed to be propotional to industrial output, while that of households is proportional to the household composite consumption. These are denoted by;

$$WG_i = RWG_i \cdot X_i \ (i=1,2,3), \quad WGH = RWGH \cdot C \qquad (16)$$

where **WG_i**:waste discharge of industry i, **RWG_i**:marginal waste discharge of industry i, **WGH**:household waste discharge, **RWGH**:household marginal waste discharge.

(4)Waste Treatment Activities

Waste treatment activities, like industries, treat and dispose of waste inputting intermediate goods, labor and capital. The technologies of treatment activities are

Leontief type with respect to intermediate inputs and, Cobb-Douglas type for labor and capital inputs. Constant returns to scale is assumed to the technology. The optimal behavior of treatment activities is supposed to minimize operating costs under a given quantity of waste with a certain ratio to be treated. The behavior of the S-activities is expressed as follows:

$$\underset{(x1i,\,x2j,\,x3i,\,L2i,\,K2i)}{\mathrm{Min}} \sum_{i=1}^{3} p_i \cdot x_{ij} + (1+tp_{2j})(w \cdot L_{2j} + r \cdot K_{2j}) \qquad (j=1,2,3) \qquad (17)$$

$$\text{s.t.} \quad WT_j = RWT_j \cdot WG_j \qquad (j=1,2,3) \qquad (18)$$

$$WT_j = \mathrm{Min}\{\frac{1}{a^2_{0j}} f_{2j}(L_{2j},K_{2j}), \frac{x_{1j}}{a^2_{1j}}, \cdots, \frac{x_{3j}}{a^2_{3j}}\} \qquad (j=1,2,3) \qquad (19)$$

$$f_{2j}(L_{2j},K_{2j}) \equiv A_j L_{2j}^{\alpha 2j} K_{2j}^{(1-\alpha 2j)} \qquad (j=1,2,3) \qquad (20)$$

where $\mathbf{x_{ij}}$:intermediate input from industry i to S-activity j, $\mathbf{tp_{2j}}$:net indirect tax rate imposed on S-activity j, $\mathbf{L_{2j}}$:labor input, $\mathbf{K_{2j}}$:capital input, $\mathbf{WT_j}$:waste treated by S-activity j, $\mathbf{RWT_j}$:self-treatment rate of industry j, $\mathbf{a^2_{0j}}$:value added ratio in S-activity, $\mathbf{a^2_{ij}}$:input coefficient in S-activity, $\mathbf{A_{2j}}$ and $\boldsymbol{\alpha}_{2j}$:technical parameters in S-activity.

As for the C/P-activity, it treats both industrial and household wastes. So we assume that the C/P-activity disposes of entire household waste and a part of industrial waste that is unable to be treated by S-activities. The behavior of C/P-activity is expressed as;

$$\underset{(x14,\,x24,\,x34,\,L24,\,K24)}{\mathrm{Min}} \sum_{i=1}^{3} p_i \cdot x_{i4} + (1+tp_{24})(w \cdot L_{24} + r \cdot K_{24}) \qquad (21)$$

$$\text{s.t.} \quad WT_4 = \sum_{j=1}^{3} RWT_{2j} \cdot WG_j + WGH \qquad (22)$$

$$WT_4 = \mathrm{Min}\ \{\frac{1}{a^2_{04}} f_{24}(L_{24},K_{24}), \frac{x_{14}}{a^2_{14}}, \cdots, \frac{x_{34}}{a^2_{34}}\} \qquad (23)$$

$$f_{24}(L_{224},K_{24}) \equiv A_{24} L_{24}^{\alpha 24} K_{24}^{(1-\alpha 24)} \qquad (24)$$

where $\mathbf{x_{j4}}$:intermediate input from industry j, $\mathbf{tp_{24}}$:net indirect tax rate imposed on C/P-activity, $\mathbf{L_{24}}$:labor input, $\mathbf{K_{24}}$:capital input, $\mathbf{WT_4}$:waste treated by C/P-activity, $\mathbf{RWT_{2j}}$:treatment ratio, $\mathbf{a^2_{04}}$:value added ratio in C/P-activity, $\mathbf{a^2_{i4}}$:input coefficient, $\mathbf{A_{24}}$ and $\boldsymbol{\alpha}_{24}$:technical parameters in C/P-activity.

The above-mentioned specification yields the following conditional labor and capital demand functions for the S- and C/P-activities.

$$LD_{2j} = (\frac{(1-\alpha_{2j})r}{\alpha_{2j} \cdot w})^{\alpha 2j} \frac{a^2_{0j} WT_j}{A_{2j}}, \quad KD_{2j} = (\frac{\alpha_{2j} \cdot w}{(1-\alpha_{2j})r})^{(1-\alpha 2j)} \frac{a^2_{0j} WT_j}{A_{2j}} \qquad (j=1,\cdots,4) \qquad (25)$$

(5)The Government, the External Sector, and Balance of Investment/Savings

These are expressed as the following balance of payments, though detailed explanations are skipped for page constraint.

- **the government**

$$\sum_{i=1}^{3} p_i \cdot CG_i + TrGH + WTC + TrGO + SG$$
$$= ty \cdot Y + \sum_{i=1}^{3} tp_{1i}(w \cdot LD_{1i} + r \cdot KD_{1i}) + \sum_{i=1}^{4} tp_{2i}(w \cdot LD_{2i} + r \cdot KD_{2i}) + TrOG \qquad (26)$$

where **CGi**:government consumption expenditures on good j, **TrGH**:current transfers to households, **WTC**:expenditures on C/P-activity, **TrGO**:current transfers to the external sector, **SG**:government savings, **TrOG**:current transfers from the external sector.

- **the external sector**

$$\sum_{i=1}^{3} p_i \cdot EX_i + TrOH + TrOG + KI + LI + SO = \sum_{i=1}^{3} p_i \cdot EM_i + TrGO + KIO + LIO \tag{27}$$

where $\mathbf{EX_i}$:export of good i, $\mathbf{EM_i}$:import of commodity i, **SO**:savings of the external sector, **LIO**:labor income transfers to the external sector ($=l_o \cdot w \cdot LS$), **KIO**:property income transfers to the external sector ($=k_o \cdot r \cdot kS$).

- **balance of investment/savings**

$$SH + SG + SO + \sum_{i=1}^{3} DR_{1i} + \sum_{i=1}^{4} DR_{2i} = \sum_{i=1}^{3} p_i \cdot I_i \tag{28}$$

where $\mathbf{DR_{1i}}$:capital depreciations of industry i, $\mathbf{DR_{2i}}$:capital depreciations of waste treatment activities, $\mathbf{I_i}$:demand for capital good produced by industry i.

(6)Commodity Prices

At first, the cost composition in industry j is;

$$p_j X_j = \sum_{i=1}^{3} p_i x_{ij} + (1+tp_{1j})(w \cdot LD_{1j} + r \cdot KD_{1j}) + q_j WT_j + q_4 WT_{2j} \qquad (j=1,2,3) \tag{29}$$

where $\mathbf{x_{ij}}$:intermediate input from i to j industry, $\mathbf{q_j}$:price of S-activity service j, $\mathbf{q_4}$: price of C/P-acitivity service.

Similarly, the cost composition in waste treatment activities are;

$$q_j WT_j = \sum_{i=1}^{3} p_i x_{ij} + (1+tp_{2j})(w \cdot LD_{2j} + r \cdot KD_{2j}) \qquad (j=1,2,3,4) \tag{30}$$

where $\mathbf{x_{ij}}$:intermediate input of waste treatment activities.

Moreover, the amount of treated waste $\mathbf{WT_j}$ is a function of industrial output while $\mathbf{WT_4}$ is a function of both industrial output and household consumption. These lead thus to the following equalities.

$$WT_j = RWT_j \cdot RWG_j \cdot X_j \quad (j=1,2,3), \qquad WT_4 = \sum_{j=1}^{3} RWT_{2j} \cdot RWG_j \cdot X_j + RWGH \cdot C \tag{31}$$

We have thereby average costs in treating waste as follows:

$$\begin{aligned} q_j WT_j / X_j &= q_j \cdot RWT_j \cdot RWG_j \\ &= RWT_j \cdot RWG_j \Big(\sum_{i=1}^{3} p_i x_{ij} + (1+tp_{2j})(w \cdot LD_{2j} + r \cdot KD_{2j})\Big)/WT_j \\ &= RWT_j \cdot RWG_j \Big(\sum_{i=1}^{3} p_i a^2_{ij} + (1+tp_{2j})(w \cdot ld_{2j} + r \cdot kd_{2j})\Big) \qquad (j=1,2,3) \end{aligned} \tag{32}$$

$$q_4 WT_{2j} / X_j = RWT_{4j} \cdot RWG_j \Big(\sum_{i=1}^{3} p_i a^2_{i4} + (1+tp_{24})(w \cdot ld_{24} + r \cdot kd_{24})\Big) \qquad (j=1,2,3) \tag{33}$$

where $a^2_{ij} \equiv x_{ij}/WT_j$, $ld_{2j} \equiv LD_{2j}/WT_j$, $kd_{2j} \equiv KD_{2j}/WT_j$.

Since marginal cost equals average cost in equilibrium, and Leontief technology is assumed for intermediate and waste disposal service inputs, commodity prices must satisfy the following equation.

$$\begin{aligned} p_j &= \Big(\sum_{i=1}^{3} p_i x_{ij} + (1+tp_{1j})(w \cdot LD_{1j} + r \cdot KD_{1j}) + q_j WT_j + q_4 WT_{2j}\Big)/X_j \\ &= \sum_{i=1}^{3} p_i a^1_{ij} + (1+tp_{1j})(w \cdot ld_{1j} + r \cdot kd_{1j}) + RWT_j \cdot RWG_j \Big(\sum_{i=1}^{3} p_i a^2_{ij} + (1+tp_{2j})(w \cdot ld_{2j} + r \; kd_{2j})\Big) \\ &\quad + RWT_{2j} \cdot RWG_j \Big(\sum_{i=1}^{3} p_i a^2_{i4} + (1+tp_{24})(w \cdot ld_{24} + r \cdot kd_{24})\Big) \qquad (j=1,2,3) \end{aligned} \tag{34}$$

We have then commodity prices as in equation (35), given the wage and capital return rates.

$$P=(I-A^{1'}-RWT\cdot RWG\cdot A^{2'}-RWT_2\cdot RWG\cdot A^{3'})^{-1}\ [(1+tp_{1j})(w\cdot ld_{1j}+r\cdot kd_{1j})$$
$$+(1+tp_{2j})(w\cdot ld_{2j}+r\cdot kd_{2j})+(1+tp_{24})(w\cdot ld_{24}+r\cdot kd_{24})] \quad (35)$$

where **P**:commodity price vector, $\mathbf{A^{1'}}$:transposed input coefficient matrix, **RWT**:diagonal matrix whose principal minors are RWT_j, **RWG**:diagonal matrix whose principal minors are RWG_j, $\mathbf{A^{2'}}$:transposed input coefficient matrix of S-activity, $\mathbf{RWT_2}$:diagonal matrix whose principal minors are RWT_{2j}, $\mathbf{A^{3'}}$:transposed input coefficient matrix of C/P-activity.

Moreover, we can express prices of waste treatment services by using commodity prices as follows:

$$q_j=\sum_{i=1}^{3} p_i a^2_{ij}+(1+tp_{2j})(w\cdot ld_{2j}+r\cdot kd_{2j}) \qquad (j=1,2,3,4) \quad (36)$$

(7)Market Equilibrium Condition

From the formulation of the model mentioned above, the market equilibrium conditions in the model can be denoted as follows:

- **commodity market**

$$(I-A^1-RWT\cdot WG\cdot A^2-RWT_4\cdot WG\cdot A^3)\cdot X+EM=C+CG+I+EX \quad (37)$$

- **waste self-treatment market**

$$WT_i=RWT_i\cdot WG_i \quad (i=1,2,3) \quad (38)$$

- **waste C/P-treatment market**

$$WT_4=\sum_{j=1}^{3} RWT_{2j}\cdot WG_j+WGH \quad (39)$$

- **labor market**

$$LS(p(w,r),w)=\sum_{j=1}^{3} LD_{1j}(w,r)+\sum_{j=1}^{4} LD_{2j}(w,r) \quad (40)$$

- **capital market**

$$KS=\sum_{j=1}^{3} KD_{1j}(w,r)+\sum_{j=1}^{4} KD_{2j}(w,r) \quad (41)$$

The CGE-modeling aims at finding the market clearing prices $(\mathbf{p^*_j, q^*_j, w^*, r^*})$ that satisfy the above-mentioned equilibrium conditions. The Walras law is, however, realized and commodity and waste treatment markets are always cleared due to Leontief technology, we can hence observe that the independent market is either labor or capital market. In the study the equilibrium capital return rate that clears capital market is computed applying the Newton-Raphson method.

3. Parameter Setting

In this section, we explain parameter setting for functions used in the model including Cobb-Douglas production functions and CES utility function. In the CGE-modeling, however, the benchmark data set is regarded to be in long-run equilibrium. Therefore, parameters applied in the model must just reproduce the benchmark year data set. So we employ the calibration method that implies to set parameters via solving non-statistical equations for unknown parameters.

(1)Production Functions

Since $\mathbf{w\cdot LD_{1j}=\alpha_{1j}a^1_{0j}X_j}$ and $\mathbf{r\cdot KD_{1j}=(1-\alpha_{1j})a^1_{0j}X_j}$ are realized in value added production functions for industries and waste treatment activities, distribution parameters $\boldsymbol{\alpha}_{ij}$ are solved. Efficient parameters $\mathbf{A_{ij}}$ are solved by using such a relation $\mathbf{A_{1j}=a^1_{0j}X_j/(LD_{1j}{}^{\alpha_{1j}}KD_{1j}{}^{(1-\alpha_{1j})})}$. Parameter estimates are shown in Table 1.

(2)Utility Functions

There are two exogenous parameters in the CES utility function, that is, elasticity of substitution between consumption and leisure, and share parameter. The value of elasticity of substitution is applied as ν =0.95623 which was estimated in Miyata, Sato and Takahashi[1]. Then the share parameter is obtained from solving the unknown parameter contained in the composite consumption function. Parameters in Cobb-Douglas sub-utility functions are directly calculated from equation (14) by employing the benchmark data set. Parameters estimated are depicted in Table 2.

(3)Marginal Waste Discharge and Treatment Rate

Marginal Waste discharges of industries and households, and treatment rates are set up in Table 3.

Other parameters/variables are briefly explained in Table 4.

4. Simulation Cases and Modifications of the Model

In this section, some numerical experiments are carried out focusing on the introduction of charging waste discharge, technical change in waste generation/treatment activities and promotion of recycling activities etc. Nine cases are examined here as presented in Table 5. The model, however, has to be appropriately modified for carry-

Table 1. Parameters in Production Function

Industries/ Activities	A_i	α_i	Rate of Value Added
Primary Industry	1.57915	0.18222	0.60661
Secondary Industry	2.15356	0.62367	0.39262
Tertiary Industry	2.03023	0.61326	0.71468
S-activity for Prim. Ind.	18581.7	0.49851	0.71469
S-activity for Sec. Ind.	202.288	0.30803	0.49270
S-activity for Ter. Ind.	220.161	0.40040	0.70159
C/P-activity	183.996	0.80097	0.79113

Table 2. Parameters in Utility Function

Commodity	Share Parameter
Composite Commodity	0.43973
Leisure	0.56027
Commodity of Prim. Ind.	0.02091
Commodity of Sec. Ind.	0.28039
Commodity of Ter. Ind.	0.69870
Elasticity of Substitution	0.95623

Table 3. Marginal Waste Discharge and Rate of Treatment

Sectors	Marginal Waste Discharge	Rate of Waste Treatment by S-Activity	Rate of Waste Treatment by C/P-Activity
Primary Industry	6.68512	0.99834	0.00087
Secondary Industry	1.81205	0.76295	0.12949
Tertiary Industry	0.29203	0.97766	0.01262
Households	0.66594	0.0	1.0

Table 4. Other Parameters/Variables

Variables	Contents
Direct taxes	Household income is regarded as a direct tax base, then the marginal rate of direct tax is estimated as 0.19288.
Household savings	Household savings are assumed to be proportional to post-direct tax full income, then marginal saving ratio is estimated as 0.09403.
Net indirect taxes	These are defined as indirect taxes minus subsidies. The tax base of net indirect taxes is set up as pre-tax factor income.
Government consumption expenditures	Nominal government consumption expenditures are proportional to government income, then expenditures on commodities are calculated by multiplying total expenditures by shares in the benchmark year data.
Transfers to the external sector	Transfers of labor and capital incomes, and government current transfers to the external sector are assumed to be proportional to labor, capital, and government incomes produced in Hokkaido, respectively.
Exports/Imports	Nominal values of exports and imports are given as constant.
Others	Transfers of labor and capital incomes, and current transfers from the external sector to Hokkaido's households and government are assumed to be exogenous constants.

Table 5. Simulation Cases

Cases	Contents
S.Case	Values of the benchmark year data.
Case 1	Household waste discharge is charged at a rate of 40yen per 10kg.
Case 2	Direct taxes which are the same to the sum of waste charges and direct taxes in Case 1 are imposed on households.
Case 3	The ratios of industrial waste to outputs are decreased by 10% in industries, respectively.
Case 4	The ratio of household waste to consumption is decreased by 10%.
Case 5	Operating costs in the S-activities are reduced by 10%.
Case 6	Operating costs in the C-activity are reduced by 10%.
Case 7	A free recycling which lowers inputs from the secondary industry by 10% is intoduced to industries.
Case 8	A recycling which cut down 10% of inputs from the secondary industy is introduced to industries. The recycled goods are assumed to be supplied by the tertiary industry.
Case 9	A free recycling which reduces household consumption of virgin commodities by 10% is introduced to households.

ing simulations. Modifications of the model are briefly summarized as follows.

(1) Case 1

We consider, in this case, two effects of charging household waste discharge. That is, they are reduction effect on waste discharge and depressing effect on household income. Household waste discharges are reduced by charging with an elasticity, and a household payment of charges constitutes a part of government income. The model is accordingly modified as follows.

First, it is assumed that discharging waste improves households' amenity and sanitary condition. Thus it is further supposed that households maximize their utility function of a composite of general good and waste discharge, and leisure, given the commodity prices, waste charge, wage rate, and capital return rate.

Second, households maximize subutility function of a composite good and waste discharge under the given composite of general good and waste discharge.

Finally, the composite commodity is divided into three commodities produced by industries through optimizing the value of sub-subutility function.

These three nested hierachical optimization problems are mathematically formulated as follows:

$$\text{①}\max \ \{(1-\beta)^{1/\nu} CW^{(\nu-1)/\nu} + \beta^{1/\nu} F^{(\nu-1)/\nu}\}^{\nu/\nu-1} \tag{42}$$

$$\text{s.t. } p_{cw} \cdot CW + (1-ty)(1-l_o)w \cdot F = (1-ty)FI - SH \tag{43}$$

$$\text{②}\max_{C,WG4} \ CW(C, WG_4) \quad \text{s.t. } p \cdot C + p_w \cdot WG_4 = (1-ty)Y - SH \tag{44}$$

$$\text{③}\max_{C1,C2,C3} \ C(C_1, C_2, C_3) = \prod_{j=1}^{3} C_j^{\alpha_j} \quad (\sum_{j=1}^{3} \alpha_j = 1) \qquad \text{s.t. } \sum_{j=1}^{3} p_j \cdot C_j = (1-ty)Y - p_w \cdot WG_4 - SH \tag{45}$$

where **CW**:consumption/waste discharge composite good, $\mathbf{p_{cw}}$:price of composite good, **CW(C,WG₄)**:utility of consumption and waste discharge, $\mathbf{p_w}$:charge of waste discharge.

Moreover, using the waste charge elasticity of demand for composite consumption commodity, $\boldsymbol{\mu}$, waste discharges are set up as follows:

$$WG_4 = (1+p_w/p)^{-\mu} \ RWG_4 \cdot C \tag{46}$$

Applying the budget constraint in (44), demand for composite consumption good and waste discharges are derived as follows:

$$C = \frac{(1-ty)Y-SH}{p+RWG_4 \cdot (1+p_w/p)^{-\mu} p_w}, \quad WG_4 = \frac{(1-ty)Y-SH}{(p/RWG_4)(1+p_w/p)^{\mu}+p_w} \tag{47}$$

Further, the utility function which yields the system of demands (47) through utility maximization should have the following mathematical form.

$$CW(C,WG_4)=(C+D\cdot WG_4)EXP(\int_0^D \frac{dz}{(1+z)^{\mu}/RWG_4+z}), \quad D\equiv(\frac{RWG_4\cdot C}{WG_4})^{1/\mu}-1 \tag{48}$$

Under this utility function, the price of **CW**, p_{cw}, is calculated as follows:

$$p_{wc}=P\cdot EXP(\int_0^{p_w/p} \frac{dz}{(1+z)^{\mu}/RWG_4+z}) \tag{49}$$

Koshimoto[3] reported that a relation between charges on and variation in waste discharges was expressed as a decrease of 6.195g in per household waste discharges for a charge of 1yen/10kg. According to the fact, we set up **p_w=40yen/10kg** as an average rate of charging in several Hokkaido's cities and towns already introduced, and μ = **148.657.** If we set **p_w=0** in this specificaton, then it is easy to see that **CW=C, p_{cw}=p** and **$WG_4=RWG_4\cdot C$.** One can thus see that the formulations made in Section 2 are still effective. For further detailed discussions, see Varian[4] and Miyata[5].

(2) Case 2

In this case, the sum of direct taxes and household waste charge payments in Case 1 is assumed. Then the direct tax rate is adjusted so as to equate direct taxes to the sum. The new direct tax rate is calculated through iteration, given the following initial tax rate.

$$ty_o'=(TH+p_w\cdot WG_4)\cdot ty/TH \tag{50}$$

where **ty_o'**:initial direct tax rate, **ty**:direct tax rate in Case 1, **TH**:direct tax revenue in Case 1, **$p_w\cdot WG_4$**:household waste charge payments in Case 1.

The finial value of direct tax rate is calculated as **ty'=0.1933** which shows 0.06% up as compared with **ty=0.1927** in Case 1.

(3)Case 9

It is assumed in the case that there was a household preference change in which optimal household commodity consumption was reduced by 10%, but leisure consumption was increased as compared to the Standard Case. Thus the utility maximization problem is modified as follows:

$$\max_{C,F} \{(1-\beta')^{1/\nu}C'^{(\nu-1)/\nu}+\beta'^{1/\nu}F'^{(\nu-1)/\nu}\}^{\nu/\nu-1} \tag{51}$$

$$s.t.\ p\cdot C'+(1-ty)(1-l_o)w\cdot F'=(1-ty)FI-SH \tag{52}$$

It is further supposed that commodity and leisure demands derived from (51) and (52) should satisfy the following equations.

$$C'=0.95C, \quad F'=F+(p/(1-ty)(1-l_o)w)\cdot 0.05\cdot C \tag{53}$$

where **C** and **F** are optimal commodity consumption and leisure in the Standard Case.

These lead to the following equality.

$$\frac{C'}{F'}=\frac{\beta'}{1-\beta'}(\frac{(1-ty)w}{p})^{\nu} \tag{54}$$

Table 6. Modifications of the Model for Other Cases

Cases	Modification of the Model
Cases 3 & 4	Marginal waste discharges, RWG_1, are decreased by 10%.
Cases 5 & 6	Input coefficients are decreased by 10% as well as the efficient parameters in Cobb-Douglas production functions are multiplied by 10/9, respectively
Case 7	The input coefficient on secondary industry good is decreased by 10% in each industry, then the same value is added to the value added rate in each industry.
Case 8	Intermediate inputs from the secondary industry are reduced by 10%, while those from the tertiary industry are increased by the same volume in industries, respectively. Price of recycled commodity inputted is, therefore, the same as that of tertiary industry commodity.

Assume that elasticity of substitution ν is unchanged, then β' can be solved from (54) as β'**=0.65387**. One can observe in the new share parameter that the household preference to leisure becomes larger than that in Table 2.

Modifications for the other cases are summarized in Table 6.

5. Simulation Results

As depicted in Table 5, nine cases are examined through numerical experiments. Table 6 shows simulation results of some key variables. In the table, figures in the Standard Case (=the benchmark year data) are represented as real values while those in other cases are illustrated as variation ratios to the Standard Case. Simulation results are briefly summarized in the subsequent context.

(1)Cases 1 and 2

The results of Case 1 show that discharge of household waste significantly decrease by 25% of that in Standard Case, because of charging the household waste discharge. The charges directly reduce the amount of household consumption, however, decrease the demand for the C/P-activity as well. The decrease in the demand leads to a shift of labor and capital to industries, resulting in a slight increase in household income. The leisure demand increases but a decrease in household consumption results in a reduction in household utility, that is, EV shows -8.6 billion yen.

Case 2 examines the effects of a taxation of the sum of direct taxes and waste charges in Case 1 on households. The taxation does not significantly affect household waste dischrge as a slight decrease by 0.06%. Also the taxation more moderately depresses household consumption expenditures than in Case 1. The government gains more revenues resulting in an increase in government consumption expenditures. Industrial outputs and gross prefectural products, however, show decreases. The decrease in household consumption derived by the taxation more affects the household utility than by an increase in the household leisure demand, leading to a negative EV of -5.1 billion yen.

As mentioned above, it can be concluded that charging household waste dischage is more effective than direct taxation from the viewpoint of reduction in waste discharge, but less effective from a welfare point of view.

(2)Cases 3 to 6

Case 3 treats a technical structure in waste generation. If a waste generation per output of industries decreased, the reduction resulted in a decrease in demand for S-activities. Labor and capital shift then to industries, resulting in decreases in commodity prices. As a result, both household consumption and leisure demand raise, and EV shows a positive value of 13.6 billion yen.

Case 4 focuses on the structure of households' waste generation. Since the ratio of amount of waste to composite cunsumption is decreased, C/P-activity tends to be smaller but industries get larger due to a shift of production factors. The reduction in the C/P-activity does not, however, decrease production costs of industries. This leads to a slight raise in a price of consumption good. Further, real consumption does not increase resulting in a slightly negative EV.

Case 5 examines the effects of a technical cahange in the S-activities. The assumed technical change reduces production costs in industries, and production factors employed by S-activities shift to industries. This leads to an increase in waste discharges in addition to outputs despite a decrease in nominal outputs. Real household consumption also increases, resulting in a positive EV of 12.5 billion yen.

A technical progress is assumed in the C/P-activity in Case 6. By assumption, treatment costs are decreased by approx.10%. The reduction in costs makes lower the price of secondary industry commodity since the industry purchases much C/P-treatment services. The shift of factors to industries expands production, but the equilibrium labor supply is lower than that in the Standard Case, leading to a positive EV.

(3)Cases 7, 8, and 9

In Case 7, free recycling activities, which operate without cost, are introduced to industries. This implies a technical change with economy of intermediate inputs. A decrease in intermediate inputs from the secondary industry reduces the size of secondary industry, but grows the value added, resulting in an expansion of household income and consumption. The increase in household income leads to a positive EV of 8.6 billion yen despite a decrease in household leisure demand. The total waste dischage is less than that in the Standard Case since the reduction in industrial waste exceeds the increase in household waste.

Case 8 supposes that recycled goods are supplied by the tertiary industry. Thus secondary industry products are substituted by tertiary goods resulting in a decrease in the secondary industry. Commodity prices get lower as well as household consumption grows. But an expansion in labor demand of the tertiary industry decreases more household utility than in Case 7 since EV shows 1.5 billion yen. Further the total waste is also reduced.

Table 2. Simulation Results of Key Variables (in variation ratio to Standard Case)
(unit: in %. Household waste charges and EV are in million yen.)

variables	Real values in S. Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
industrial outputs	22,932,737	0.060	-0.015	-0.945	-0.851	-0.958	-0.837	-3.613	-1.265	-6.723
outputs of waste clearing act.	202,982	-3.643	-0.020	-8.512	-1.409	-6.924	-2.995	-6.853	-5.830	-7.334
household income	14,642,893	0.021	0.012	0.001	0.003	-0.002	0.005	-0.049	-0.106	-5.183
household consumption	9,625,270	-0.078	-0.070	0.000	0.003	-0.002	0.005	-0.050	-0.107	-6.120
labor demand	7,407,223	-0.027	-0.016	-0.017	-0.005	-0.012	-0.010	0.076	0.184	-6.267
government income	7,079,202	0.148	0.142	0.006	0.003	0.003	0.006	0.010	-0.188	-2.681
capital investment	4,251,462	0.278	0.040	-0.060	0.076	-0.100	0.117	-0.188	-0.221	-5.269
waste discharged	35,371,908	-2.268	-0.010	-8.984	-0.880	0.084	0.063	-4.748	-3.858	-3.956
primary industry	13,112,662	0.087	-0.005	-9.897	0.031	0.084	0.062	-4.559	-4.004	-3.026
secondary industry	15,394,144	0.133	-0.002	-9.882	0.044	0.086	0.089	-6.838	-6.182	-5.028
tertiary industry	3,643,357	-0.014	-0.012	-9.964	0.002	0.036	0.007	-0 915	2.966	-3.245
households	3,221,745	-25.876	-0.063	0.131	-10.003	0.123	0.005	0.135	0.126	-3.425
price of primary good	1.0000000	0.018	-0.012	-0.093	0.011	-0.098	0.015	-0.286	-0.363	-4.673
price of secondary good	1.0000000	0.012	-0.007	-0.262	0.007	-0.236	-0.019	-0.238	-0.289	-2.987
price of tertiary good	1.0000000	0.010	-0.006	-0.079	0.006	-0.082	0.008	-0.161	-0.207	-2.656
rate of capital returns	1.0000000	0.026	-0.016	-0.053	0.015	-0.069	0.031	-0.385	-0.499	-6 587
price of consumption good	1.9895589	0.011	-0.007	-0.131	0.006	-0.125	0.001	-0.185	-0.233	-2.791
price of prim. S-act. service	108	0.013	-0.008	-0.078	0.007	-10.071	0.008	-0.199	-0.255	-3.225
price of sec. S-act. service	9,167	0.014	-0.009	-0.084	0.008	-10.078	0.011	-0.224	-0.287	-3.664
price of ter. S-act. service	8,905	0.014	-0.009	-0.071	0.008	-10.067	0.012	-0.221	-0.283	-3.647
price of C/P-act. service	9,112	0.006	-0.004	-0.045	0.004	-0.045	-9.997	-0.103	-0.131	-1.657
household waste charges	0	9.552	0	0	0	0	0	0	0	0
equivalent variation	0	-8,558	-5,140	13,607	-71	12,496	1,037	8,624	1,547	29,888

Note1: Labor demand in Standard Case is denoted in a quantity which yields services of one million yen

Note2: In Standard Case, waste discharge is in ton, prices of waste clearing services are in million yen/ton, and others are in million yen.

Note3: Variation ratios are in nominal term except labor demand and waste discharge.

Case 9 assumes a free recycling by households. The recycling reduces household consumption of virgin products leading to decreases in industrial outputs. Commodity prices significantly fall as compared to other cases. The depression in the economy, as a natural consequence, much reduces waste discharge. EV is, however, largely raised by 30 billion yen since a preference change is assumed in the case.

6. Concluding Remarks

The study has constructed a CGE model internalizing an interaction of the economy and waste discharge/treatment, then carried out some numerical simulations. The study can be appreciated as a very effective approach in environmental economics/studies, however, there may be some points that should be improved. First, a more detailed classification of industries is pointed out. Such a classification could lead to a more fruitful examination of the waste/economic interaction. Second, functional forms of production and/or utility functions and parameters applied to them might significantly influence the simulation results. Therefore, a more careful examination of functional forms and parameters would be necessary.

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廃棄物－経済システムの一般均衡分析　-応用一般均衡モデルによるアプローチ-

宮田　譲

本研究は１９８５年の北海道を対象とし、廃棄物と経済との相互依存関係を分析するものである。そのために、廃棄物発生、除去活動を内生化した応用一般均衡モデルを構築している。モデルは産業（３分類）、家計、政府、道外部門、産業廃棄物自己除去活動（３分類）、廃棄物委託・行政除去活動から成っている。産業は生産活動に伴い産業廃棄物を発生させ、家計は消費活動によって一般廃棄物を発生させる。これらは廃棄物除去活動により、処理・処分されるが、その際、生産活動と同様に生産要素の投入を行う。このモデルを用いて家計廃棄物の有料化、リサイクル推進などが所得、価格、厚生水準などにどの様な影響を与えるのかをシミュレーション分析している。

A GENERAL EQUILIBRIUM ANALYSIS OF THE WASTE-ECONOMIC SYSTEM - A CGE MODELING APPROACH -

by Yuzuru MIYATA

This study aims to analyze the interaction between the waste discharge/treatment and the economy of Hokkaido in 1985. So as to implement the objective, we construct a computable general equilibrium(CGE) model internalizing waste generation/treatment activities. The model consists of several economic activities including; industries, households, the government, the external sector, industrial waste self-treatment activites, and waste contract/public treatment activity. Industries generate waste in production, while households discharge waste in consumption. These wastes are cleared by waste treatment activities inputting, like industries, production factors. Effects of charging waste, promoting recycling etc. on the economy including income, prices, welfare level are examined by applying the model.