AN INTERTEMPORAL GENERAL EQUILIBRIUM ANALYSIS OF THE WASTE-ECONOMIC SYSTEM

By Yuzuru MIYATA **

1. Introduction

The author has proposed Waste-Economic Accounting Matrix that expresses interaction between economic activities and waste generation/treatment, and then constructed a CGE model based on the accounting matrix [1]. In that study, economic effects of charging household waste, technological progress of waste treatment activities etc. are examined through comparative static numerical simulations.

Current studies of environment/economic interaction have, however, tended to examine how an economy can grow with maintaining and/or improving an environmental condition. A recent report of *United Nations "Integrated Environmental and Economic Accounting"* advocates *"Eco-GDP"* which is defined as a gross value added neccesarry for maintaining a national environmental level [2]. Those studies suggest the importance of a dynamic nature of environmental and economic interaction.

Taking acconut of the dynamic nature, this study extends our previous static model into an intertemporal CGE model [3), 4)], and then examines a possibility of sustainable development of the economy of Hokkaido, Japan.

2. The Model

(1)Assumptions of the model

① Economic agents are; households, 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).

② S-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, i.e. primary, secondary, and tertiary S-activities for the treatment of waste generated by respective industries.

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

③ Nine 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.

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

⑤ The simulation period is 20 years interval of 1986 to 2005.

(2)Subjective behavior of economic agents

a)Industries

Industries employ intermediate goods, labor and capital minimizing production costs, and produce commodities discharging waste. 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.

Most of waste are treated by S-activities, but a part of it is disposed of by C/P-activity.These treatment services are inputted to industries like intermediate 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:

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

subject to

$$X_j = Min\{\frac{1}{a^1_{0j}} f_{1j}(L_{1j}, K_{1j}),\ \frac{x_{1j}}{a^1_{1j}}, \cdots, \frac{x_{3j}}{a^1_{3j}},\ \frac{WT_j}{RWT_j \cdot RWG_j},\ \frac{WT_{2j}}{RWT_{2j} \cdot RWG_j}\} \tag{2}$$

$$f_{1j}(L_{1j}, K_{1j}) \equiv A_{1j} L_{1j}^{\alpha 1j} K_{1j}^{(1-\alpha 1j)} \tag{3}$$

where p_i : price on commodity i, x_{ij} : intermediate input from industry i to j, tp_{1j} : net indirect tax rate (indirect tax rate - 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 on self-treatment service j, WT_j : the amount of wastes of industry j treated by S-activity, q_4 : price on contract/public treatment service, WT_{2j} : the amount of wastes of industry j treated by C/P-activity, X_j : output of industry j, a^1_{0j} : value added rate of industry j, a^1_{ij} : intermediate input coefficient of industry j, RWT_j : self-treatment rate in industry j, RWT_{2j} : contract/public treatment rate in industry j, RWG_j : marginal waste discharge of industry j (see also equation (6)), A_{1j} , α_{1j} : technical parameters in industry j

The technological constraint (2) implies that industries must input waste treatment services in production process like production factors. Taking account of the Leontief technology in industrial intermediate and waste treatment service inputs, we obtain the following conditional labor and capital demands.

$$LD_{1j} = [\frac{(1-\alpha_{1j})r}{\alpha_{1j} \cdot w}]^{\alpha 1j} \frac{a^1_{0j} X_j}{A_{1j}} \quad and \quad KD_{1j} = [\frac{\alpha_{1j} \cdot w}{(1-\alpha_{1j})r}]^{(1-\alpha 1j)} \frac{a^1_{0j} X_j}{A_{1j}} \tag{4}$$

Further the zero profit condition is realized in industries under perfect competition.

$$profit = p_j \cdot X_j - \sum_{i=1}^{3} p_i \cdot a^1_{ij} X_j - (1+tp_{1j})\{w \cdot LD_{1j} + r \cdot KD_{1j}\} - q_j\, WT_j - q_4\, WT_{2j} = 0 \tag{5}$$

b)Waste generation

Waste generation is classified into two types, namely, industrial and households wastes. They are assumed to be proportional to industrial output and households composite consumption, respectively. Thus we have;

$$WG_j = RWG_j \cdot X_j \quad (j=1,2,3) \quad and \quad WGH = RWGH \cdot C \tag{6}$$

where WG_j : the amount of waste discharge by industry j, RWG_j : marginal waste discharge of industry j, WGH: households waste discharge, $RWGH$: marginal waste discharge of households

Further self-treated waste of industry j, WT_j, contract/public treated waste, WT_{2j}, are formulated as follows.

$$WT_j = RWT_j \cdot WG_j \quad and \quad WT_{2j} = RWT_{2j} \cdot WG_j \quad (j=1,2,3) \tag{7}$$

c)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 some ratio to be treated. The behavior of the S-activities is expressed as follows:

$$\underset{(x1i,\, x2j,\, x3i,\, L2i,\, K2i)}{Min} \sum_{i=1}^{3} p_i \cdot x_{ij} + (1+tp_{2j})(w \cdot L_{2j} + r \cdot K_{2j}) \quad (j=1,2,3) \tag{8}$$

$$subject\ to\ WT_j = RWT_j \cdot WG_j \ \text{and}\ WT_j = Min\{\frac{1}{a^2_{0j}} f_{2j}(L_{2j}, K_{2j}),\ \frac{x_{1j}}{a^2_{1j}}, \cdots, \frac{x_{3j}}{a^2_{3j}}\} \tag{9}$$

$$f_{2j}(L_{2j}, K_{2j}) \equiv A_{2j} L_{2j}^{\alpha 2j} K_{2j}^{(1-\alpha 2j)} \tag{10}$$

where x_{ij} : intermed. input of S-activity j from industry i, tp_{2j} : net indirect tax rate for S-activity j, L_{2j} : labor input of S-activity j, K_{2j} : capital input of S-activity j, WT_j : waste treated by S-activity j, RWT_j : self-treatment rate in industry j, a^2_{0j} : value added rate in S-activity j, a^2_{ij} : intermediate input coefficient in S-activity j, A_{2j} , α_{2j} : technical parameters in S-activity j

As C/P-activity treats both industrial and household wastes, it may be assumed that C/P-activity disposes of entire households waste and a part of industrial waste which is unable to be treated by S-activities. The behavior of C/P-activity is very similar to that of S-activity, therefore description of C/P-activity is skipped to spare space. (Readers may refer to Miyata [5] for details.)

d)Households

Households share an aggregate CES utility function of composite consumption and leisure, and consume them so as to maximize the integration of discounted utility function over time. Then the composite goods are divided into three types of commodities (i.e. primary, secondary, and tertiary).

The budget constraint imposed on households is as follows. First, househoulds income is composed of full income which is defined as income obtained if households supplied their entire labor endowment, post depreciation capital income, current transfers from the government, labor income, property income, and current transfers from the external sector. A part of wage and capital incomes is transferred to the external sector.

Direct taxes are subtracted from the households full income. Then households allocate their disposable income on consumption and leisure. It is assumed that households social security contributions are regarded as direct taxes, for simplicity. The balance of *income and expenditures* is saved financing capital investment. Then household behavior may be expressed as follows:

$$\underset{C,F}{Max} \int_0^\infty [(1-\beta)^{1/v} C^{(v-1)/v} + \beta^{1/v} F^{(v-1)/v}]^{v/2(v-1)} e^{-\xi t} dt \tag{11}$$

$$\text{subject to } \dot{KS} = (1-ty)FI/p_I - (p/p_I)C - (1-ty)(1-l_o)(w/p_I)F \tag{12}$$

$$FI \equiv (1-l_o)w \cdot E + (1-k_o)(r-p_I\delta)KS + LI + KI + TrGH + TrOH \tag{13}$$

where β : share parameter, v : elasticity of substitution, C : composite consumption, F : leisure, ξ : subjective discount rate, KS : capital stock endowed by households, ty : direct tax rate, FI : households full income, p_I : price on capital goods, p : price on composite consumption goods, w : wage rate, l_o : rate of wage income transferred to the external sector, E : initial labor endowmwnt of households, k_o : rate of capital income transferred to the external sector, δ : capital depreciation rate, LI : wage income transferred from the external sector (exogenous variable), KI : capital income transferred from the external sector (exogenous variable), $TrGH$: current transfers from the government to households, $TrOH$: current transfers from the external sector to households

In the above, gross investment, Ip , for capital accumulation is written as $Ip=\dot{KS}+\delta KS$. Let us further specify Ip as a *Leontief* function of commodities produced by each industry.

$$Ip = min\{Ip_1/b_1, Ip_2/b_2, Ip_3/b_3\} \quad \text{where } b_i > 0, \sum_{i=1}^{3} b_i = 1 \tag{14}$$

It is assumed that the gross investment is made minimizing the investment costs, $\sum_{i=1}^{3} p_i Ip_i$, thus it leads to $Ip_i = b_i Ip \ (i=1, 2, 3)$. Denoting the price of capital goods by p_I , $p_I = \sum_{i=1}^{3} b_i p_i$ is realized since $p_I Ip = \sum_{i=1}^{3} p_i \cdot b_i Ip$.

Let us now introduce a *current value Hamiltonian* in order to solve the intertemporal optimization problem (11) to (13).

$$H(t) \equiv [(1-\beta)^{1/v} C^{(v-1)/v} + \beta^{1/v} F^{(v-1)/v}]^{v/2(v-1)} + \lambda [(1-ty)(1-l_o)(w/p_I)(E-F) + (1-ty)\{(1-k_o)(r/p_I - \delta)KS + LI + KI + TrGH + TrOH\} - p \cdot C] \tag{15}$$

where λ : costate variable associated with KS

Necessary and sufficient conditions for the controllable variables in (11) maximizing the objective function include; equation (12), $\dot{\lambda} = -\partial H/\partial KS + \xi\lambda$, maximization of *Hamiltonian* by C and F at each time, and finally, the transversality condition.

These can be expressed as the following mathematical forms.

$$\dot{\lambda} = \lambda[\xi - (1-ty)(1-k_o)(r/p_I - \delta)] \tag{16}$$

$$C=(1-\beta)[(1-\beta)+\beta(\frac{p}{(1-ty)(1-l_o)w})^{v-1}]^{(2-v)/(v-1)}(p_I/\lambda p)^2 \quad (17)$$

$$F=\beta[(1-\beta)(\frac{p}{(1-ty)(1-l_o)w})^{1-v}+\beta]^{(2-v)/(v-1)}[p_I/\lambda(1-ty)(1-l_o)w]^2 \quad (18)$$

$$LS=E-F \quad \text{and} \quad \lim_{t\to\infty}\lambda\cdot KS\cdot e^{-\xi t}=0 \quad (19)$$

where $\boldsymbol{LS}$: labor supply of households

Further composite good is divided into industrial commodities through maximizing the *Cobb-Douglas* sub-utility function.

$$Max \prod_{j=1}^{3} C_j^{\alpha_j} \quad (\sum_{j=1}^{3}\alpha_j=1) \qquad subject\ to \ \sum_{j=1}^{3} p_j\cdot C_j=p\cdot C \quad (20)$$

where $\boldsymbol{C_j}$: consumption of commodity i, $\boldsymbol{p_j}$: price of commodity j

Therefore we obtain the consumption demand for industries as;

$$C_j=\alpha_j\, p\cdot C/p_j \quad (1,2,3) \quad where \quad p=\prod_{j=1}^{3}(\frac{p_j}{\alpha_j})^{\alpha_j} \quad (21)$$

e)Balance of investment/savings

In the model, private capital accumulation is internalized by maximizing the integration of present value of the utility function. In the actual economy, however, there are other investments including public and housing investments etc. We should therefore take them into account. Here we suppose that other investments are financed by savings of the government and the external sector, yielding the following balance of investment and savings.

$$\sum_{i=1}^{3} p_i I_i=SG+SO \quad (22)$$

where $\boldsymbol{I_i}$: demand for commodity i by other investment, $\boldsymbol{SG}$: savings of the government, $\boldsymbol{SO}$: savings of the external sector

Savings of the government and the external sector are determined by budget constraints imposed on both sectors. Explanations of the constraints are, however, skipped because of page limitation. (See Miyata [5] for details.)

3. Derivation of Equilibrium

In this section, we briefly mention the derivation of equilibrium solution of the model. First, given an initial capital stock held by households, *KS(0)*, the amount of capital stock at each time is determined by capital accumulation process (12). Then given the total labor endowment, *E(t)*, households consumption and labor supply at each time are determined through (17) to (19). We thus obtain the equilibrium condition on each market at each time as below. Note that the dynamics is introduced only in household behavior, but the following conditions imply the dynamic optimization of production and waste treatment as well as households consumption because households hold both labor and capital.

commodity market

$$X_i+EM_i=\sum_{j=1}^{3}a_{ij}^{1}X_j+\sum_{j=1}^{4}a_{ij}^{2}WT_j+C_i+CG_i+Ip_i+I_i+EX_i \qquad (i=1,2,3) \quad (23)$$

labor market

$$LS=\sum_{i=1}^{3}LD_{1j}+\sum_{i=1}^{4}LD_{2j} \quad (24)$$

capital rental market

$$KS=\sum_{i=1}^{3}KD_{1j}+\sum_{i=1}^{4}KD_{2j} \quad (25)$$

waste generation/treatment

$$WT_i=RWT_i\cdot RWG_i\cdot X_i \qquad (i=1,2,3), \qquad WT_4=\sum_{i=1}^{3}RWT_{2i}\cdot RWG_i\cdot X_i+RWGH\cdot C \quad (26)$$

In the study, effects of waste generation/treatment on economic growth are examined through computing capital stock, economic flow variables, and waste to satisfy the above-mentioned equilibrium conditions by iteration. The iteration is made on the capital return rate letting labor be the numeraire ($w=1$).

4. Parameter Setting and Simulation Cases

(1)Parameter setting

Paramers in the model are calibrated by employing 1985 Hokkaido's actual data. Because of page constraint, details of parameter setting are skipped. The objective function (11) and the differential equation (12) are converted into discrete difference equations for numerical computation. Setting initial endowments of labor and capital as 1986 values, simulations are carried out with the target year of 2006. Equation (11) is now transformed into;

$$\underset{C,F}{Max} \sum_{t=1986}^{2005} [(1-\beta)^{1/v} C^{(v-1)/v} + \beta^{1/v} F^{(v-1)/v}]^{v/2(v-1)} /(1+\xi)^{(t-1986)} + \theta\ KS(2006)/(1+\xi)^{20} \tag{27}$$

The final term in the objective function implies an evaluation function of the asset held by households at the target year. This term also plays a role of determining the final state condition of the costate variable λ (t).

Parameters applied in the model are presented in Tables 1 to 4. The subjective discount rates at 1986 to 1994 in Table 4 are the actual values of market interest rate at those years in Japan, and those after 1994 are fixed at 4 %.

(2)Simulation cases

Simulations are made focusing on technological and cost conditions on waste treatment activities, promotion of recycling, and introduction of charges on household waste. Scenarios assumed in simulations are summarized in Table 5. Moreover the model is appropreately modified so as to implement the simulations. The modifications are summarized as follows.

a)Cases 1 and 2

Marginal waste discharges, RWG_i and $RWGH$, are increased by 10%.

b)Case 3

The rate of intermediate inputs from the secondary industry is decreased by 10 % in each industry, while the value added rate is increased to keep its output unchanged at the value of 1985.

c)Case 4

The intermediate input coefficient on secondary goods is decreased by 10 % in each industry, and that on tertiary commodities is raised to hold its output level in 1985.

d)Case 5

This case examines two kinds of effects of charging households waste. They are a reduction effect on waste discharge and a depressing effect on households income. Households waste discharges are reduced by charging with an elasticity, and households payments for charges constitutes a part of the 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 goods and waste discharge, and leisure, given the commodity prices, waste charges, wage rate, and capital return rate.

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

Finally, the composite commodity is divided into three commodities produced by industries through optimizing the sub-subutility function in (20).

These three nested hierachical optimization problems are described in continuous format as follows:

① $$\underset{C,F}{Max} \int_0^\infty [(1-\beta)^{1/v} CW^{(v-1)/v} + \beta^{1/v} F^{(v-1)/v}]^{v/2(v-1)} e^{-\xi t}\, dt \tag{28}$$

$$subject\ to\quad \dot{KS}=(1-ty)FI/p_I -(p_{cw}/p_I)CW-(1-ty)(1-l_o)(w/p_I)F \tag{29}$$

② $$\underset{C,WGH}{Max}\ CW(C,WGH) \qquad subject\ to\quad p\cdot C+p_w\cdot WGH=p_{cw}\ CW \tag{30}$$

③ $Max\ C(C_1, C_2, C_3) = \prod_{j=1}^{3} C_j^{\alpha_j}$ subject to $\sum_{j=1}^{3} p_j \cdot C_j = p \cdot C$ (31)

where **CW** : composite good of consumption and waste, **p_{cw}**: price on CW, **$CW(C, WGH)$** : utility function of general consumption and waste discharge, **p_w** : charges on waste discharge

Moreover, using the waste charge elasticity of demand for composite consumption commodity, μ , waste discharges are set up as follows:

$$WGH = (1+p_w/p)^{-\mu} \cdot RWGH \cdot C \tag{32}$$

Applying the budget constraint in (30), demand for composite consumption goods and waste discharges are derived as follows:

$$C = \frac{p_{cw}CW}{p + RWGH \cdot (1+p_w/p)^{-\mu} p_w} \quad \text{and} \quad WGH = \frac{p_{cw}CW}{(p/RWGH)(1+p_w/p)^{\mu} + p_w} \tag{33}$$

Koshimoto [6] reports that a relation between charges on and variation in waste discharges is expressed as a decrease of 6.195g per households waste discharge for a charge of 1yen/10kg. According to the fact, we set up p_w=40yen/10kg as an average rate of charging already introduced in some regions in Hokkaido,yield-

Table 1. Parameters in Production Function

activities	A_i	α_i	rate of value added
pri. indus.	1.57915	0.18222	0.60661
sec. indus.	2.15356	0.62367	0.39262
ter. indus.	2.03023	0.61326	0.71468
primary S-activity	18581.7	0.49851	0.71469
secondary S-activity	202.288	0.30803	0.49277
tertiary S-activity	220.161	0.40040	0.70159
C/P-activity	183.996	0.80097	0.79113

Table 2. Parameters in Utility Function

commodities	share parameter
composite goods	0.43973
leisure time	0.56027
primary goods	0.02091
secondary goods	0.28039
tertiary goods	0.69870
elasticity of substitution	0.95623

Table 3. Marginal Waste Generation and Rate of Treatment

activity	marginal waste discharge	rate of self-treatment	rate of C/P-treatment
pri. ind.	6.68512	0.99834	0.00087
sec.ind.	1.81205	0.76295	0.12949
ter. ind.	0.29203	0.97766	0.01262
house-holds	0.66594	0.0	1.0

Table 4. Subjective Discount Rate and Evaluation Parameter for Capital Stock at the Target Year

year	'86	'87	'88	'89	'90
dis. rate	5.505	4.936	4.930	5.782	7.697
year	'91	'92	'93	'94	'95
dis. rate	6.989	5.552	4.414	4.047	4.0
year	after '95	evaluation parameter for capital stock θ =1/5550			
dis. rate	4.0				

Note: Subjective discount rates are in % .

Table 5. Simulation Cases

cases	description of cases
Base Case	No modification is made on the model. Model outputs show the same as those in the benchmark year.
Case 1	Waste discharge per output is increased by 10 % in each industry.
Case 2	Household waste discharge per consumption is increased by 10 % .
Case 3	A cost free recycling which reduces 10 % intermediate inputs from the secondary industry is introduced.
Case 4	A recyling which reduces 10 % intermediate inputs from the secondary industry is introduced to every industry. Recycled goods are assumed to be supplied by the tertiary industry.
Case 5	40yen/10kg is charged on households waste discharge.

ing μ =148.657. For further details of discussion, see Miyata [5]

5. Simulation Results

In this section we summarize the simulation reults of 5 cases comparing with the base case. Simulation results of some key variables are illustrated in Figures 1 to 15. We start with explanation of the intertemporal path in the base case. Note that variables in monetary term are expressed at constant prices in 1985. Further details of the simulation results are available on demand upon the author.

(1)The base case

a)Gross prefectural product (GPP)

Hokkaido's gross product (i.e.industries' and waste treatment activities' gross value added) shows 14.4 trillion yen at 1986, then grows at an annual rate of 1.46 % showing 19 billion yen at 2005. The growth path of GPP, as depicted in Figure 1, shows a moderate increase during 1986 to 1989, then a slightly fast raise from 1989 to 1992 when the growth rate shows a lower figure after that time. This trend is interpreted as a reflection of the intertemporal consumption pattern influenced by higher subjective discount rates during 1989 to 1992.

Industries' gross product is 14.3 trillion yen at 1986, and becomes 18.8 trillion yen at 2005 with a growth rate of 1.46 % . The trend is almost the same as that of the total GPP because the economic size of waste treatment activities is only 1 % of Hokkaido's entire economy.

Looking at gross product by industry, the growth rates of the three industries are calculated as 1.70 % , 1.59 % , and 1.37 % , respectively.

As for waste treatment activities, their initial GPP is 140.4 billion yen at 1986, then becomes 186.2 billion yen at 2005 with an annual growth rate of 1.5 % . The growth rate is slightly greater than that of industries. The sectoral growth rates are; 1.77 % for primary S-activity, 1.56 % for secondary S-activity, 1.36 % for tertiary S-activity, and 1.47 % for C/P-activity.

b)Waste discharge

The total volume of waste discharge is 40.45 million tons at 1986, and reaches to 53.39 million tons at 2005 with a growth rate of 1.47 % . The growth path depicted in Figure 4 shows a similar manner to that of GPP. This is resulted from the waste discharge of each industry that is assumed to be proportional to its output in the model.

Figures 5 to 8 show the trend of waste discharge by industry and by household. It is observed that the trends of waste of industries and households are almost the same as those of GPP and the intertemporal consumption pattern, respectively.

c)Households consumption

Households consumption shows an annual growth rate of 1.21 % during 19 years, which is slightly lower than that of GPP. The growth path presented in Figure 9 shows, however, a varied trend. It decreases during 1989 to 1991 after which it tends to grow again. This can be interpreted as follows. Since the subjective discount rates within the interval are set up higher than those in other years, the present values of households utility during the periods are evaluated to be lower resulting in a depression of consumption expenditures. This raises households savings (=capital accumulation) so as to enjoy the future utilities under lower discount rates.

d)Households labor supply

Households labor supply grows from 8.14 million in 1986 to 8.20 million in 2005 with a slight growth rate of 0.03 % . The manner of intertemporal labor supply also indicates a varied trend as presented in Figure 10. It falls during the period of 1986 to 1988, grows to 1992 when it turns to show a moderate decrease to 2001, and again increases to 2005. These are interpreted as follows. From 1986 to 1988, the decrease in labor supply is mainly caused by a substitution of labor by capital followed by capital accumulation. From 1989 to 1992, leisure demand is controlled by higher subjective discount rates. Up to 2001, labor supply is substituted by capital, and finally its slight increase up to 2005 is brought about by the evaluation of final capital stock.

Anyway, the labor endowment is assumed to be constant over the simulation terms. Therefore those results demonstrate that the economy can grow by the production effect of capital accumulation unless labor forces are much supplied.

e)Prices

Prices internalized in the model are wage rate, capital return rate, commodity prices, and prices on waste treatment services. Since labor is assumed to be numeraire, we explain the behavior of capital return rate and

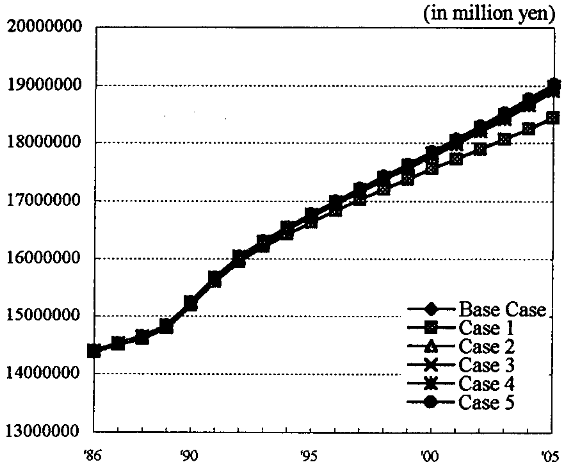

Figure 1. Prefectural Gross Product

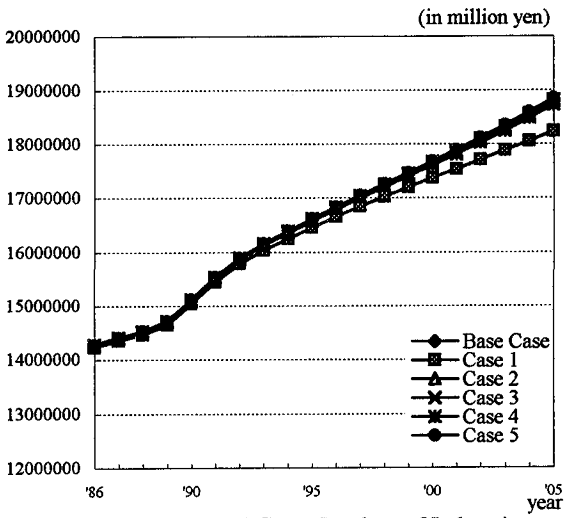

Figure 2. Total Gross Product of Industries

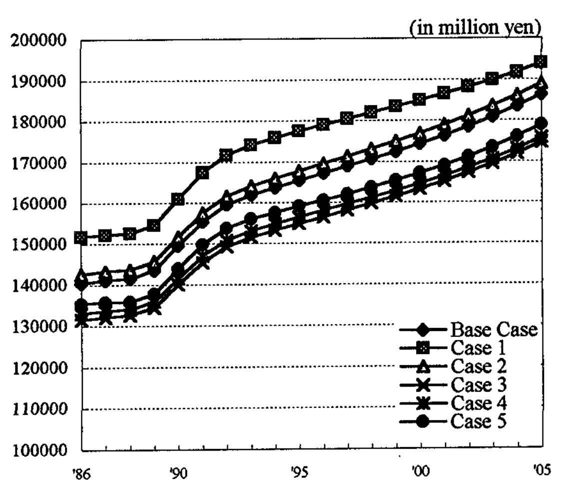

Figure 3. Total Gross Product of Waste Treatment Activities

price index on composite consumption goods. As other prices behave like these, explanations of those are skipped here.

Looking at the capital return rate in Figure 12, its value uniformly falls from 14.43 % in 1986 to 7.91 % in 2005. However its value is almost the same during the period of 1989 to 1991, even a slight increase in 1990. These can be attributed to a decrease in marginal rate of technical substitution caused by the capital accumulation. A slight raise in 1990 is considered to be followed by an increase in labor supply resulted from a higher subjective discount rate in that year.

In Figure 13, the price on composite consumption goods behaves like the capital return rate though its value differs. This is resulted from the matter that commodity prices are determined by price equations which are in linear combination of capital return and wage rates, and the price on composite is derived from commodity prices.

f)Indirect Utility and Social Welfare Functions

Indirect utility shows an increasing trend through the simulation term with its value of 8,163 in 1986 and 8,588 in 2,005. As illustrated in Figure 14, however, its intertemporal path shows a decreasing trend from 1989 to 1991 resulted from the changes in households consumption and labor supply in the interval.

Figure 15 depicts a manner of integration process of social welfare function at each year. Thus the value of the curve at the final year indicates the value of social welfare function. Since curves in all cases are very similar to each other, the curve only in the base case is drawn here.

Since the social welfare function contains a summation of discounted indirect utility over the simulation term, the curve shows an uniformly increasing trend. The value of social welfare function is calculated as 116,434 with 111,298 of the integration of discounted utility and with 5,136 of evaluation of capital stock at the final year.

Taking account of the results in the base case, let us summarize the results in each case in the subsequent context.

(2)Case 1

In this case, industrial marginal waste discharges are assumed to be increased by 10 % . As depicted in Figure 3, waste treatment activities grow more as compared to the base case, resulting in a shift of labor and capital to waste treatment activities. It further makes the industrial growth slower. On the other hand, households consumption increases and labor supply decreases leading to a greater households indirect utility than that in the base case. This may be, as shown in

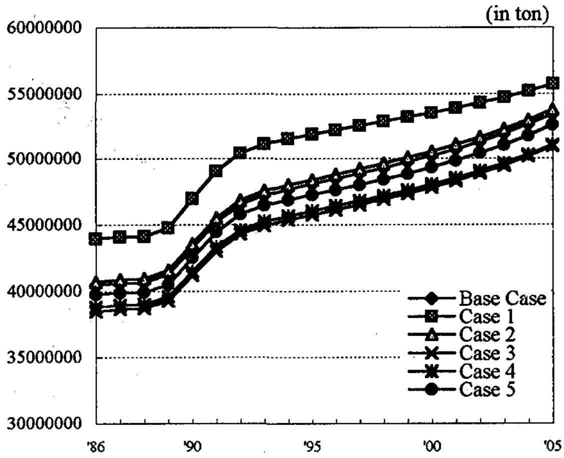

Figure 4. Total Waste Generation

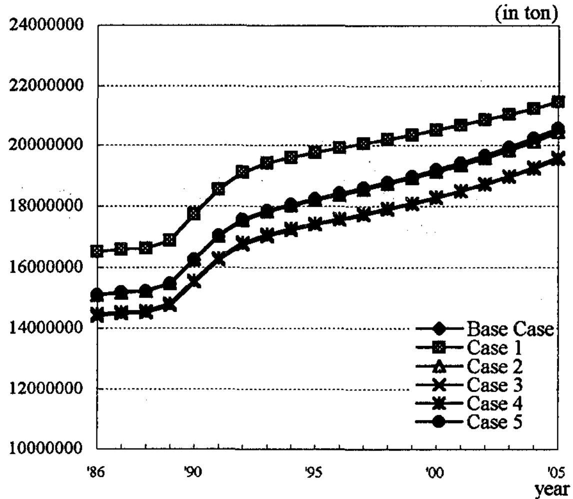

Figure 5. Waste Generation By Primary Industry

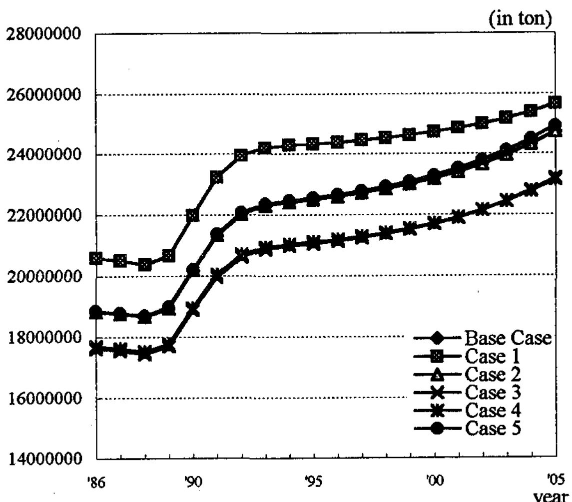

Figure 6. Waste Generation by Secondary Industry

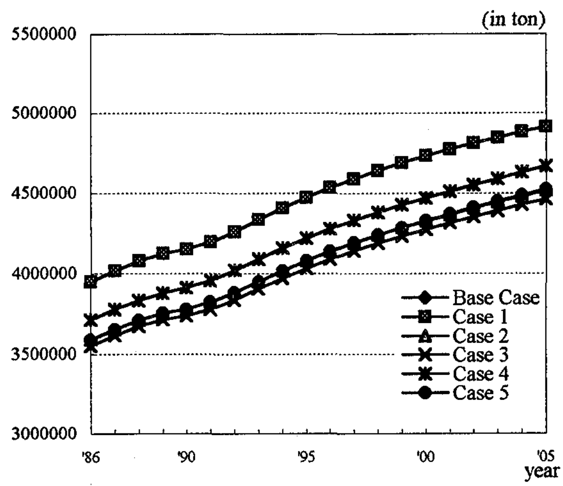

Figure 7. Waste Generation by Tertiary Industry

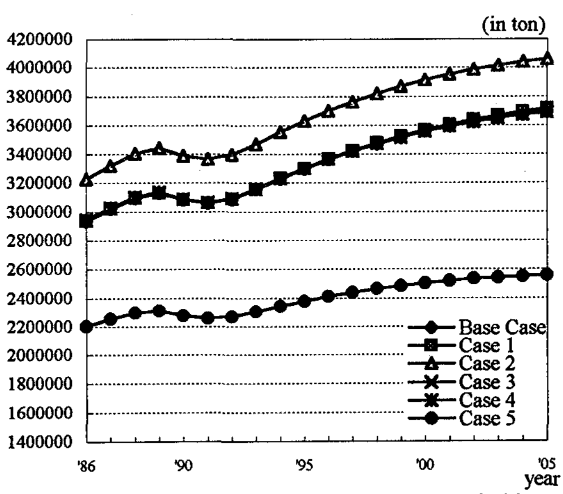

Figure 8. Waste Generation by Households

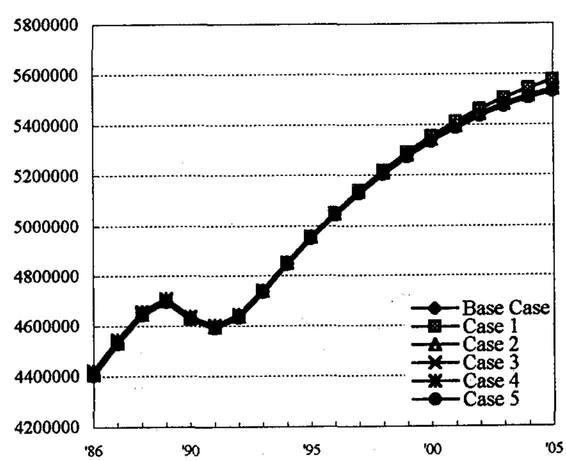

Figure 9. Household Consumption

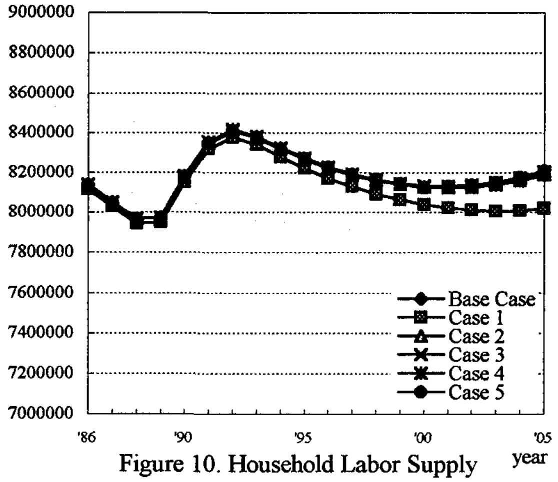

Figure 10. Household Labor Supply

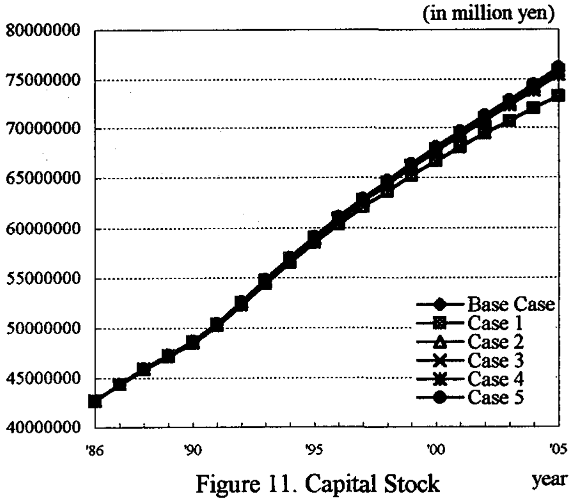

Figure 11. Capital Stock

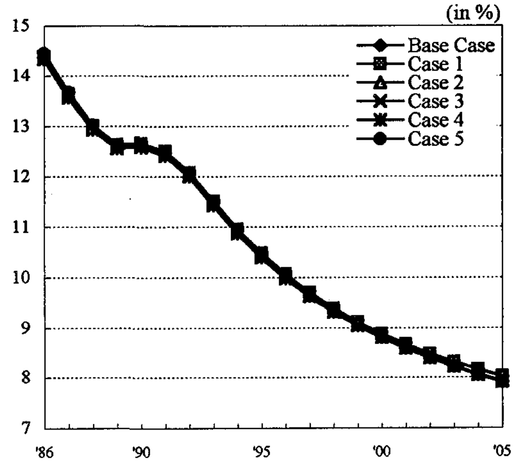

Figure 12. Capital Return Rate

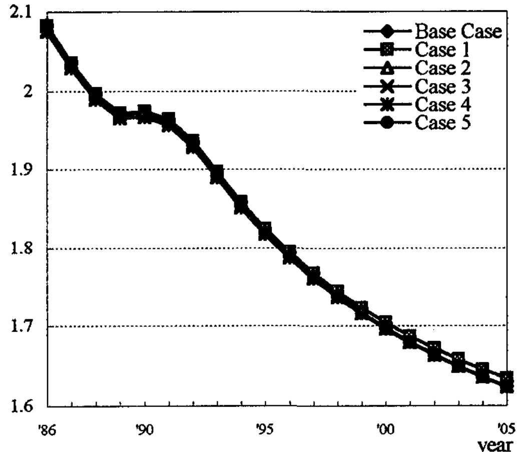

Figure 13. Price on Composite Consumption

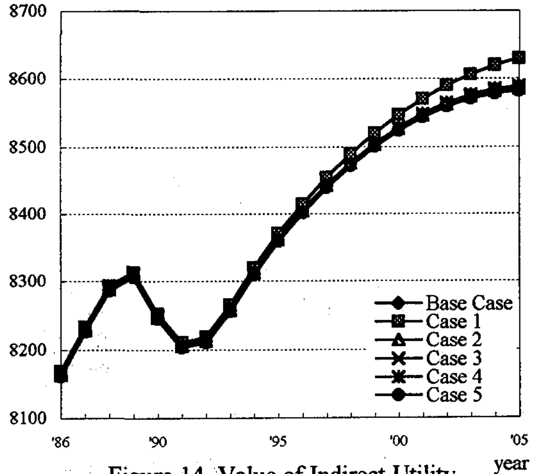

Figure 14. Value of Indirect Utility

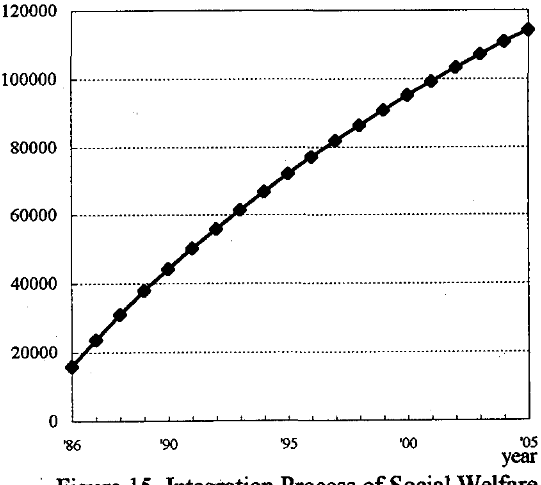

Figure 15. Integration Process of Social Welfare

Table 1, attributed to the fact that the value added rates in waste treatment activities are greater than those in industries. The value of social welfare function, which includes evaluation of capital stock, however, shows a greater figure at the terminal year. It can thus be concluded that the welfare level in the case is lowered as compared to the base case.

(3)Case 2

In the case, waste volume per household consumption is increased. Since the share of volume of households waste to the total in 1986 is estimated about 7 %, changes in the case are the smallest among all other cases.

Looking at gross product, that of C/P-activity is 3.91 % greater at 2005 than in the base case since households waste is entirely treated by C/P-activity. While the growths of industries and S-activities are slightly sacrificed because of a shift of production factors to C/P-activity. As most of these effects cancel each other, the indirect utility and the social welfare take almost the same values as those in the base case.

(4)Case 3

A recycling which reduces 10 % intermediate inputs from the secondary industry is introduced here. This assumption implies that each industry's demand for secondary commodities directly falls but its ratio of value added increases.

These conditions yield that gross products of industries except the primary increase lowering waste generation though the output of each industry falls. The decreases in industrial waste reduce waste treatment activities resulting in a fall of their gross products, but GPP increases. Therefore households consumption and leisure time exceed those in the base case in preceding periods leading to a greater integration of present value of utility and the social welfare than those in the base case.

(5)Case 4

The recycling in Case 3 is here further modified as that recycled goods are assumed to be supplied by the tertiary industry. Therefore intermediate demand for tertiary commodities rises while that for the secondary is decreased.

This yields the lower levels of outputs of the primary and tertiary industries as compared to the base case while that of the tertiary industry grows higher. Thus industirial wastes of the primary and the secondary decrease and that of the tertiary increases resulting in a reduction in the total waste discharge.

Following these changes, households consumption and leisure time increase though GPP decreases as compared to the base case. This further leads to the matter that the integration of present values of utility function exceeds that of the base case, and the social welfare function gets a similar value to the base case.

(6)Case 5

In this case, charging households waste discharge is introduced. It reduces households waste by about 25 % to 30 % through the simulation periods. Further it also decreases households consumption slightly because it raises the price on the composite of waste and commodities.

Decreases in households waste reduce C/P-activity resulting in shifts of production factors to other activities. Therefore gross products of industries and S-activities expand. Industrial waste discharge grows more than that of the base case, but a significant decrease in households waste lowers the total waste discharge.

However decreases in households consumption and leisure time reduce the sum of present values of utility function and the social welfare more than those in the base case. Therefore this case suggests that charging households waste significantly reduces a load on environment, but decreases the economic welfare.

6. Concluding Remarks

This study has extended the author's previous static CGE model of the waste-economic system into an intertemporal model, and then carried out some numerical experiments. Since the economic share of waste treatment activities is only about 1 % to entire Hokkaido's economy, large quantitative economic influences of them have not been observed. But this study has successfully suggested some interesting qualitative effects on welfare, prices, and industrial structure etc. resulted from changes in waste generation/treatment.

Since the model is based on optimization of economic agencies, it may not be necessarily appropriate for quantitative future forecasting. But it enables us to know how a growth path is desirable. From this point, one can consider a sustainable development of environment and economy.

This study is an initial step for the scope mentioned above, and has some points to be improved. These include updating the benchmark data set, internalizing private investment by industry, and making the industrial classification more detailed. Finally this study is financially supported by the Scientific Grant-in-Aid of the Ministry of Education, the Government of Japan (No.09247219 and No.09680547).

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廃棄物－経済システムの動学一般均衡分析*

宮田　譲**

本研究は北海道を対象として、廃棄物と経済との相互依存関係を動学的に分析するものである。このため動学的に拡張した応用一般均衡モデルを構築している。モデルは産業、家計、政府、道外部門、廃棄物除去活動から構成されている。家計は効用の現在価値総和を最大化するように消費、余暇、貯蓄の選択を行う。家計の貯蓄は資本蓄積となり、経済の動学プロセスが決定される。生産及び消費に伴う廃棄物は、除去活動により処理処分されるが、その際中間財、資本、労働を投入する。このモデルを用いて家計廃棄物有料化、リサイクル推進などが、経済成長に与える影響をシミュレーション分析している。

AN INTERTEMPORAL GENERAL EQUILIBRIUM ANALYSIS OF THE WASTE-ECONOMIC SYSTEM

By Yuzuru MIYATA **

This study examines the intertemporal interaction between economic activities and waste generation /treatment in Hokkaido, Japan. For the objective we construct an intertemporal general equilibrium (ICGE) model incorporating waste generation/treatment. Econcomic agencies included in the model are; industries, households, government, external sector, and waste treatment activities. Households determine consumption, leisure, and savings maximizing the integration of present value of utility over time. Then households savings constitute capital investment generating the economic dynamics. Wastes generated by industries and households are disposed of by waste treatment activities inputting, like industries, intermediate goods, capital, and labor. Intertemporal economic effects of charging waste discharge, promotion of recycling etc. are examined by applying the model.