Journal of Global Environment Engineering, Vol. 4, pp. 65–76, 1998

STUDY ON OPTIMAL POLLUTANT EMISSION BY EVALUATING BOTH ENVIRONMENTAL AND ECONOMIC UTILITY IN DECISION-MAKING

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Abstract

In order to reduce pollutants, it is assumed that both economic growth and environmental conservation are taken into consideration in decision-making in Japan. The optimization model, which has two objective functions: conventional economic utility by consumption and environmental utility derived from pollution, is constructed and simulated, in order to substantiate this hypothesis. From sensitivity analyses of the weight of environmental utility caused by SOx and NOx emission compared with economic utility in Japan after 1970, the value of this weight is evaluated to assess the past pollutant reduction. The changes of production activity and price of goods by introducing environmental utility are comparable with the result of the existing researches. Although the value of this weight actualized the past pollutant emission is applied to the carbon emission in the future, effective carbon reduction cannot be achieved. In order to stabilize carbon emission to the 1990 level or lower, the value of this weight should be strengthened than that of the past pollutant reduction.

KEYWORDS: *dynamic optimization model, environmental utility, air pollutant reduction*

1. Tradeoff between Economy and Environment

The environmental problems in Japan became evident as pollution problems in 1960's. Most of these problems, however, were solved through the various environmental regulations and investment for environmental preservation (environmental investment). Fig. 1 shows the change of the environmental investment in private firms and the ratio of this environmental investment to the total capital investment. Fig. 2 shows the change of expenditure for environmental preservation by governments and the ratio of this expenditure to the total budget. It is pointed out that the environmental investment had promoted the economic activity. Tab. 1 represents the influence to the economic activity in 1975 through the environmental investment from 1965 to 1975. It can be seen that the environmental investment has negative and positive effects on economic activities. The negative impacts appeared through the substitution effect, raising the price of goods. On the other hand, the positive impacts resulted from the income effect due to increase of demand for equipment to preserve environment. As a result, it is reported that these effects were offset and severe economic damages by environmental investment did not happen (Environment Agency, 1977). But these environmental investment and environmental protection policy were not always implemented for economic benefits in

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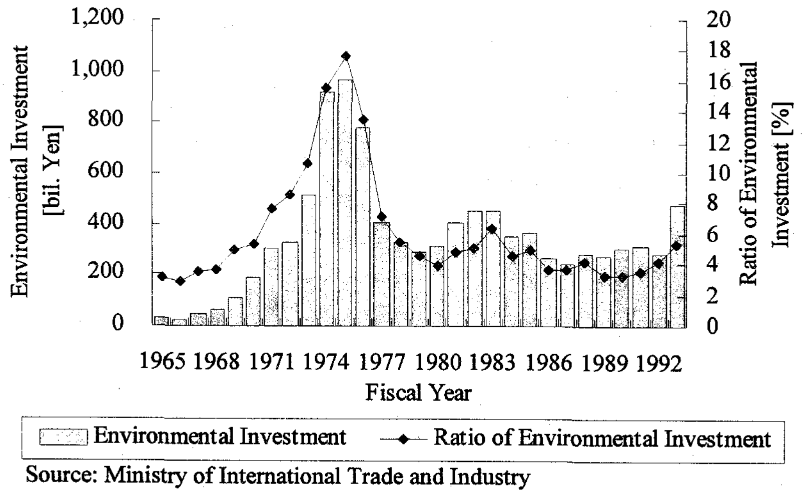

Figure 1. Change of Environmental Investment in Private Firms and Ratio of Environmental Investment to Total Capital Investment

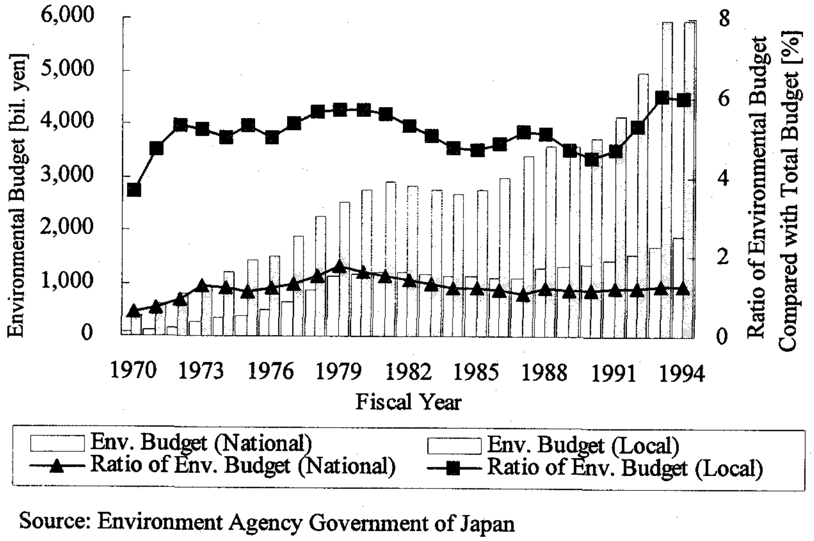

Figure 2. Change of Expenditure for Environmental Protection by Governments and its Ratio Compared with Budget

decision-making. It is likely that utility received from the environment is evaluated directly in decision-making, because there is a limit to evaluate environmental goods in monetary unit and these values are not reflected fairly in the present economic system such as 'external diseconomy'. In this paper, it is assumed that, in order to reduce pollutants, both economic growth and environmental conservation should be taken into consideration in decision-making in Japan after 1970's.

For model analyses to evaluate the global environmental problems, there are a few researches which include environmental utility, such as MERGE (Manne and Richels, 1995). This shows that the evaluation considering environmental utility is still at the preliminary

GNP at Constant Price	about 0.9% increase
Final Consumption of Households	about 0.4% increase
Capital Investment of Private Firms	about 7.4% increase
Surplus of the Nation on Current Account	about 300 bil. yen decrease
Consumer Price Index	about 1.2% increase
Wholesale Price Index	about 1.7% increase

These values are based whether the capital investment for pollution preservation in private firms from 1965 to 1975 (the sum total was 5.3 tri. yen at 1970 price) were carried out or not.

Surplus of the nation on current account is at 1970 price, and the others are at 1975 price.

Souce: Environment Agency Government of Japan(1977)

Table 1. Macro Economic Influence by Pollutant Preservation

stage.

When multiple objects, for example economic utility and environmental utility in this study, are evaluated at the same time, the multi-objective optimization, multi-objective programming are used (Ishitani and Ishikawa, 1992). In multi-objective programming theory, the tradeoff among various objectives is calculated in advance (Nakagami, 1986). In order to solve the multi-objective optimization problems, there are two methods: all variables except the main indicator are satisfied at reasonable levels, and plural objects are aggregated to one object. The first method of multi-objective optimization is the same as the optimization problem with pollution control constraints. The second method of multi-objective optimization means that, for example, damages of pollution are exchanged to the monetary term. The benefits of environmental goods are often underestimated due to the difficulties of their evaluation. Besides above methods, there is the goal programming method — the differences between objective variables and their targets are minimized (Fukukawa, 1975). This method also means that the plural objective functions satisfy their targets rather than that they are optimized. So, in this paper, both economic utility and environmental utility are taken into consideration in the objective function, and these two utilities are supposed to be weighted and summed. Through the sensitivity analyses on the weight of environmental utility compared with economic utility, the weight realized past pollution reduction is estimated.

2. Optimization Model Including both Environmental Utility and Economic Utility

At first, the features of optimal solution including both environmental utility and economic utility will be surveyed. There are some examples of the optimization model with environmental utility besides economic utility, such as Keeler et al.(1971), Foster(1973), Dasgupta(1982), and so on. The optimization problem in this paper is defined as follows;

$$Max \sum_t U(C,P) \exp(-rt) \tag{1}$$

subject to

$$\frac{dK}{dt} = f(K) - C - \delta K \tag{2}$$

$$\frac{dP}{dt} = af(K) - bP \tag{3}$$

where t: time series, r: discount rate, a: emission factor of pollutant to production, b: assimilation rate of pollutant by the environment, δ: depreciation rate of capital stock, C: consumption, P: pollutant stock, K: capital stock, U: utility function, and f: production function. Eq. 1 is the objective function that consists of environmental utility derived from environmental burdens and economic utility by consumption of economic goods. It is assumed that economic utility is an increasing function of consumption but the marginal economic utility by consumption is diminishing, that is $\partial U/\partial C > 0$, $\partial^2 U/\partial C^2 < 0$. On the other hand, environmental utility is a decreasing function of pollutants and the marginal environmental utility is decreasing by pollutants, that is $\partial U/\partial P < 0$, $\partial^2 U/\partial P^2 < 0$. These assumptions are for guarantee of convexity against above optimization problem. Eq. 2 represents that the temporary change of capital stock is the capital investment minus depreciation of capital stock. It is supposed that the outputs depend only on the capital stock and increase to capital stock, but marginal productivity of capital stock is diminishing. That is $df(K)/dK > 0$, $d^2 f(K)/dK^2 < 0$. Eq. 3 represents that the temporary change of pollutant stock is defined as discharged pollutants derived from production activities, $af(K)$, minus pollutants assimilated by the environment, bP.

The Hamiltonian current value of this optimization problem is defined as follows;

$$H = U(C, P) + \lambda[f(K) - C - \delta K] + \mu[af(K) - bP] \tag{4}$$

where λ is the shadow price of capital stock, and μ is the shadow price of pollutant. The necessary conditions for the above optimization problem are as follows:

$$\frac{dH}{dC} = \frac{\partial U}{\partial C} - \lambda = 0 \tag{5}$$

$$\frac{d\lambda}{dt} = r\lambda - \frac{\partial H}{\partial K} = r\lambda - \lambda\frac{df}{dK} + \delta K\lambda - a\mu\frac{df}{dK} \tag{6}$$

$$\frac{d\mu}{dt} = r\mu - \frac{\partial H}{\partial P} = r\mu - \frac{\partial U}{\partial P} + b\mu \tag{7}$$

Then the features of the steady equilibrium condition are analyzed, where the time differential of variables is zero. When $dC/dt = 0$ and $dK/dt = 0$, the next equations are reached respectively.

$$-\frac{\partial U/\partial C}{\partial^2 U/\partial C^2}\{\frac{df}{dK}(1 + \frac{a\mu}{\partial U/\partial C}) - r - \delta\} = 0 \tag{8}$$

$$f(K) - C - \delta K = 0 \tag{9}$$

From Eq. 8 and Eq. 9, the phase diagram of consumption and capital stock is drawn as Fig. 3. When environmental utility is considered in decision-making, the steady state equilibrium point of consumption and capital stock is changed from the point A to B, in order to reduce pollutant emission.

From $dP/dt = 0$ and $d\mu/dt = 0$, the next equations are reached respectively.

$$af(K) - bP = 0 \tag{10}$$

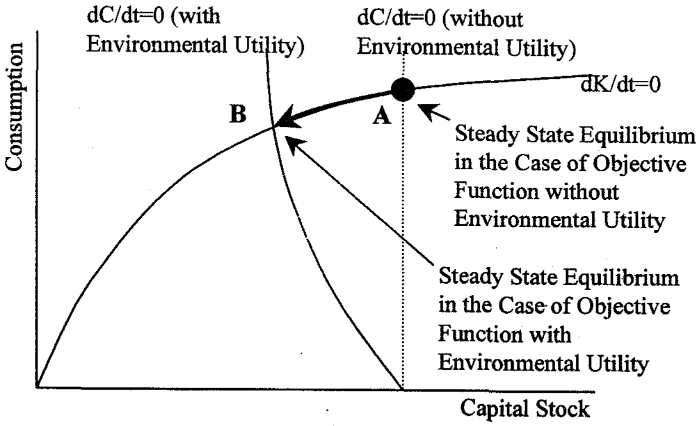

Figure 3. Phase Diagram of Consumption and Capital Stock in Steady-State Equilibrium

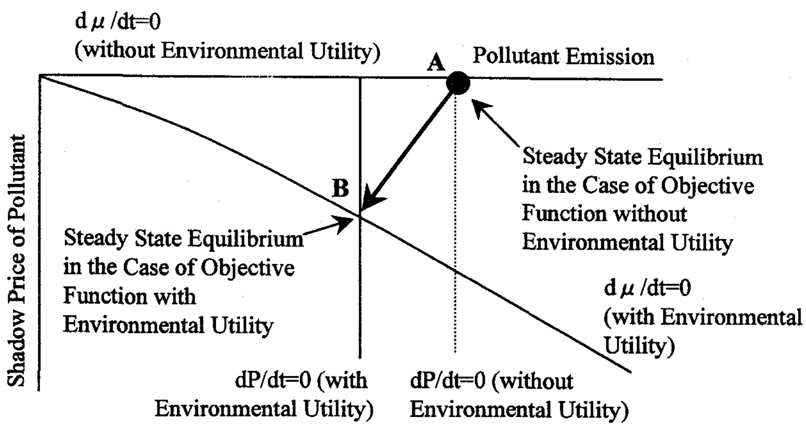

Figure 4. Phase Diagram of Pollutant Emission and Shadow Price of Pollutant in Steady-State Equilibrium

$$r\mu - \frac{\partial U}{\partial P} + b\mu = 0 \tag{11}$$

Fig. 4 shows the phase diagram of emitted pollutants and its shadow price. By consideration of environmental utility in decision-making, the pollutant emission in the steady state equilibrium is reduced from the point A to B.

3. Evaluation of Environmental Utility on Air Pollutant Reduction in Japan

3.1 Model Structure for Evaluation of Air Pollutant Reduction

In this section, the previous optimization model with environmental utility is applied to air pollution control in Japan. In order to evaluate the weight of environmental utility compared with economic utility, it is assumed that the objective function $U(C, P)$ is

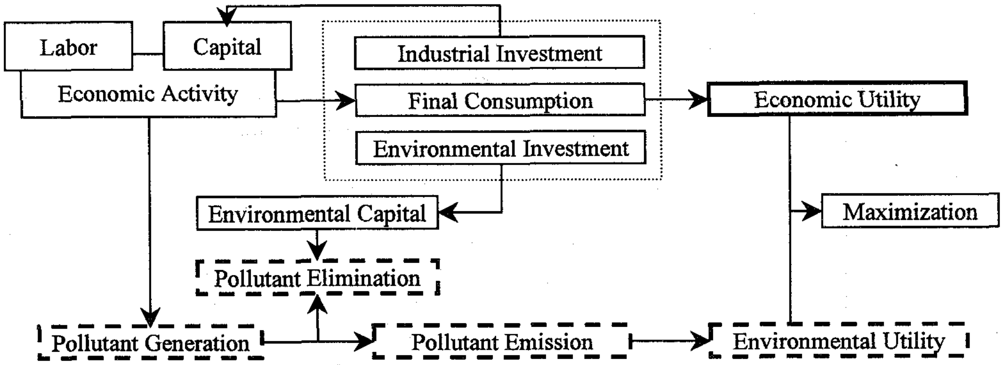

Figure 5. Economic Activity and Environment in This Model

divided into two components, environmental utility, $v(P)$, and, conventional economic utility, $w(C)$, and these two utilities are combined linearly. From the formulation of this objective function, the environmental utility and the economic utility can be substituted. As shown in previous section, $v(P)$ satisfies $dv/dP < 0$ and $d^2v/dP^2 < 0$, and $w(C)$ satisfies $dw/dC > 0$ and $d^2w/dC^2 < 0$. In this paper, it is assumed that the environmental utility function and the economic utility function satisfying these conditions are defined as follows; $v(P) = -\exp(P/P_0)$ and $w(C) = \ln(C/C_0)$, where P_0 and C_0 are the initial pollutant and consumption, respectively. That is to say, the objective function in this paper is defined as $U(C,P) = \chi v(P) + w(C) = -\chi \exp(P/P_0) + \ln(C/C_0)$, where χ is the weight of environmental utility compared with economic utility. P and C are normalized to the initial value P_0 and C_0, respectively, to coordinate the optimal solution due to variation of their dimension. This is because the optimal solution might change when the units of P and C are changed. In this model, it is assumed that the both utilities are defined to be the values of initial pollutant emission and consumption. The measurability of utility is not established. The subject in this paper is not the evaluation of the value of utility itself, but the evaluation of changes of the pollutant elimination through the different value of the weight of environmental utility compared with economic utility, χ. Unlike the previous theoretical model, pollutant flow not pollutant stock affects environmental utility function because it is very difficult to estimate the assimilation rate of pollutant by the environment. That is to say, b in the equations in the previous chapter is defined to be 0. In this analysis, it is assumed that the pollutant emission is caused by only energy consumption. So, in order to calculate the pollutant emission, the pollutant emission factor to production activity, a, is not used. In the next section, how to estimate the pollutant emission is explained. The depreciation rate of capital stock, δ, is assumed to be 5 % per year, and discount rate, r, is assumed to be 3 % per year.

Fig. 5 shows the economic system and decision-making in this model. The produced goods are supplied to the final consumption, the industrial investment, and the environmental investment. The final consumption increases economic utility, and the industrial investment also make the economic utility increase through the production activities in the future. The production activity brings increase of economic utility but, at the same time, harms environmental utility by pollutant generation. The environmental investment increases environmental utility through the reduction of pollutants.

In this paper, air pollutants, SOx and NOx are taken up as the elements of environmental utility. The reasons why these pollutants are adopted are as follows: First, it is easy to

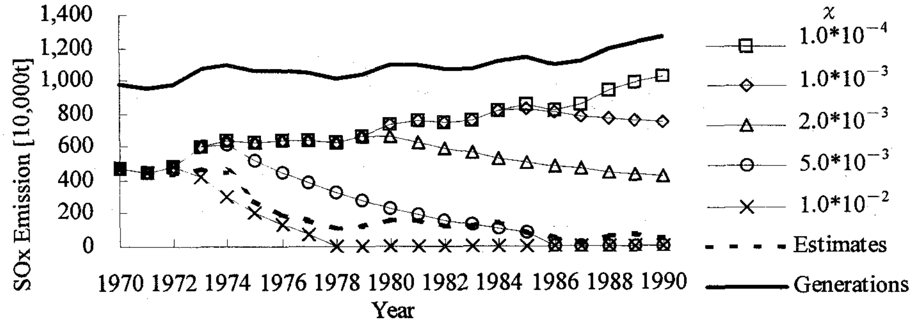

Figure 6. SOx Emission Trajectory by Scenarios

calculate the mass of these pollutants, because almost these pollutants are derived from energy consumption. Second, the air pollutants are typical of environmental burden, because the ratio of the air environment loss in Japan is 78.5 % in the year 1990, when the Green GDP is accounted by Economic Planning Agency (Japan Research Institute, 1995). Third, it is difficult to aggregate the various environmental resources such as water, air, wastes at the same time.

The term treated in this model is from the year 1970 to 1992. In this model, the production activities are aggregated because of simplicity. The inputs of production function are capital stock, which is endogenous variable, and labor, which is exogenous parameter, and these inputs are combined through the Cobb-Douglas production function.

Pollutant generations are calculated from exogenous energy input, and eliminated pollutants are determined endogenously from the equipment for environmental preservation (environmental capital stock). Although energy shift to low sulfur fuels, energy saving were very important in order to reduce pollutant emission (Kobayashi and Morita, 1997), in this paper it is assumed that all pollutant reduction were realized through the environmental investment. Pollutant emissions are calculated generated minus eliminated pollutants. Environmental utility is defined from sum of both disutility of sulfur oxidant emission and that of nitrogen oxidant emission. On the other hand, the economic utility is defined from consumption of goods. The environmental capital stock is accumulation of environmental investment. Because the environmental investment includes not only the equipment for pollutant elimination but also its running cost, maintenance cost, and other pollutant elimination cost (Environment Agency, 1993), the environmental investment contributing to SOx and NOx elimination equipment is assumed to be 20 % of each environmental investment. The relationship between the mass of the eliminated pollutants and the capital stock in the year 1990 is settled at 1.8 ton/million yen for SOx and 0.8 ton/million yen for NOx (Hondo and Uchiyama, 1993), assumed to improve 1 %/year. Although it is thought that the marginal cost of pollutant elimination increases according to the mass of the eliminated pollutant, it is supposed that the marginal cost is constant in this paper.

3.2 Estimates of Weight of Environmental Utility Compared with Economic Utility

Fig. 6 and Fig. 7 show the transitions of each pollutant emission when the weight of the environmental utility compared with the economic utility is changed. "Estimates" in Fig. 6 and Fig. 7 are the values from the regression analysis, in which the SOx and NOx emissions are

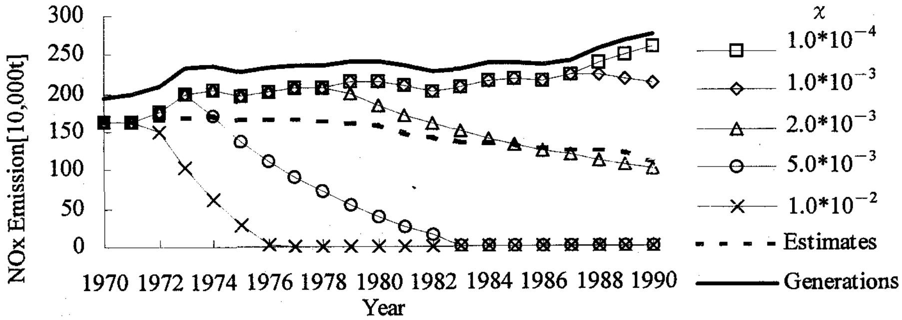

Figure 7. NOx Emission Trajectry by Scenarios

	Sulfur Oxides	Nitrogen Oxides
Estimated Pollutant Generation Potential Derived from Energy Demand (t-value)	$8.96*10^{-1}$ (2.02)	$1.91*10^{-1}$ (0.45)
Numbers of Installation of desulfurlizer or denitrofiers (t-value)	$-3.60*10^{4}$ (−6.13)	$-3.47*10^{3}$ (−2.39)
Constant Number (t-value)	$-3.82*10^{6}$ (−0.89)	$1.24*10^{6}$ (1.38)
Multiple Correlation Coefficient	0.97	0.77

Sample number = 6.
The dependent variable is the mass of each pollutant emission.
Data Source: OECD(1993), Environment Agency Government of Japan, Agency of Natural Resources and Energy

Table 2. Regression Analysis on Pollutant Emission in Japan

defined from generated pollutants and the number of equipment for each pollutant elimination. The results of this regression analysis are shown in Tab. 2.

Even if the values of the weight of environmental utility compared with economic utility are the same, the transitions of pollutants are different. It can be accounted to the differences of the mass of generated pollutants, cost effectiveness of these pollutant reductions. This result can be seen in the difference of shadow prices of pollutants. The shadow price of NOx is from twice to thrice higher than that of SOx. From above sensitivity analyses on the weight of environmental utility, χ, this weight is evaluated to be in the order of 10^{-3} in order to realize the past pollutant reduction in Japan under the assumption explained in the previous section.

It is evaluated the changes of the price of goods and GDP by comparison between objective function with environmental utility and that without it in Tab. 3. When environmental utility is considered, the shadow price of goods increases. These increases of shadow price of goods are from the substitution effects by introducing the environmental investment, and these values are almost the same as those in Tab. 1. Until the end of 1970's, GDP in the case considering environmental utility is more than that in the case without environmental utility. But after the beginning of 1980's, GDP decreases slightly compared with the case without environmental utility. From these results, both the income effects and the substitution effects by the environmental investment are offset at the beginning, but later the substitution effects

Value of Weight	Year	1975	1980	1985
1.0*10^-3	GDP	0.06 % increase	0.14 % increase	0.20 % increase
	Price Index	0.22 % increase	0.36 % increase	0.53 % increase
2.0*10^-3	GDP	0.39 % increase	0.22 % increase	0.07 % decrease
	Price Index	1.35 % increase	1.87 % increase	1.93 % increase
5.0*10^-3	GDP	0.10 % increase	0.27 % decrease	0.29 % decrease
	Price Index	1.83 % increase	1.65 % increase	1.38 % increase

These values are compared with the output from the optimization model without environmental utility.

Table 3. Changes of GDP and Price by Existence of Environmental Investment or not

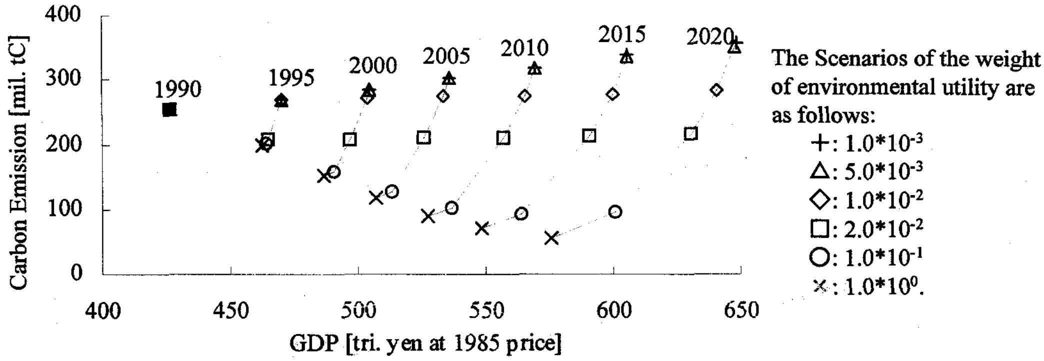

Figure 8. Relationship between Carbon Emission and GDP by Scenarios

are slightly more than the income effects to the economic activity. Because the simulation results such as price changes of goods and pollutant reduction are appropriate to actualize the past economic activity, it is concluded that not only economic utility but also environmental utility should be considered in decision-making.

3.3 Carbon Dioxide Reduction from Weight of Environmental Utility

Carbon dioxide is taken up as the element of environmental utility instead of SOx and NOx, and carbon reduction will be evaluated when the weight to actualize the past pollutant reduction is applied. In this section, not only capital and labor but also energy is considered as the input of production function. The output of production function is gross domestic product including energy cost like Global 2100 (Manne and Richels, 1992). In order to reduce carbon emission, shift to less carbon intensity energy, substitution from energy to capital or labor are supposed, and the excess costs by adopting these measures are equal to the environmental investment in Fig. 5.

The transitions of carbon emission by scenarios on the weight of environmental utility compared with economic utility are shown in Fig. 8. As the same in the case of air pollution reduction, the higher the value of the weight of the environmental utility is, the more carbon emission is reduced. But in the case of the weight to realize the past SOx and NOx reduction, almost carbon reduction will not be seen. Although it is thought that the stock effects of the environmental investment to eliminate pollutants along with the features of pollutant emissions cause these differences, these results mean that carbon reduction is more difficult than air pollutant reduction after 1970's. When the value of the weight of environmental utility, χ, is 2.0×10^{-3}, the marginal cost of carbon dioxide compared with those of SOx and NOx on the average in each investigation period is about five times and twice higher, respectively. This marginal cost of carbon dioxide become higher and higher in the future, and the marginal cost in 2020 will be about twice more expensive than that in 1995.

Fig. 8 shows the relationships between GDP and carbon emission, too. In this figure, the results of relationship between economic activity and carbon emission are expressed when different priorities of environmental protection policy in decision-making. Based on this figure, the various economic growth scenarios considering environmental benefit can be drawn in advance.

4. Conclusion

In this study, the optimization model maximizing the objective function that consists of environmental utility and economic utility is constructed, and the features of this optimization model are analyzed. In order to actualize the past sulfur oxidant and nitrogen oxidant emission, sensitivity analyses on the weight of environmental utility compared with economic utility is carried out, and its value is applied to the carbon emission in the future. The following results can be drawn:

1. Theoretically, decision-making including environmental utility to conventional economic utility decreases both the pollution level and consumption level in the steady equilibrium state.
2. In order to actualize the past SOx and NOx emission, the optimization model is constructed and simulated, whose objective function is summed $-\chi \exp(P/P_0)$ as environmental utility and $\ln(C/C_0)$ as economic utility linearly, where P is the discharged pollutant, P_0 is the initial discharged pollutant, C is the consumption of goods, C_0 is the initial consumption, and χ is the weight of environmental utility compared with economic utility. From the analyses, the value of χ is about the order of 10^{-3}.
3. When the past pollutant emission is actualized, the economic activity until the end of 1970's is promoted by the income effect of the environmental investment. After that, the influence of the substitution effect becomes more, but decrease of GDP is small.
4. Although the result of the weight for past SOx and NOx reduction is applied to the future carbon emission, the effective carbon reduction cannot be seen. If the carbon emission reduction is realized, higher value of the weight of environmental utility compared with economic utility will be needed. These differences of emission between air pollutants and carbon dioxide are caused not only by the pollutant emission factors and their cost effectiveness but also the stock effects by equipment of pollutant reduction. This means that it is much more difficult to reduce carbon emission than to reduce air pollutants after 1970's.
5. From the sensitivity analyses on the weight of environmental utility, the marginal cost of carbon dioxide compared with those of NOx and SOx in each investigation period is about twice and five times respectively, in the case of the value of the weight is 2.0×10^{-3}.

From these results, it is concluded that the past decision-making considered environmental utility to reduce sulfur oxidant and nitrogen oxidant emission, and the future decision-making will have to weight to environmental utility compared with economic utility much more in order to reduce carbon emission.

Finally, the recommendations of this study are as follows;

1. A detailed study on the shape of utility function, both environmental utility and economic utility, will be needed. And the aggregation of environmental utilities categorized differently will have to be discussed, too.
2. The effects for pollutant reduction except the environmental investment, such as energy shift to lower sulfur fuel, will have to be considered, because these elements were important to reduce pollutant.
3. In this paper, the value of the weight of environmental utility compared with economic utility is constant through the periods. But it is thought that this value may increase accordingly as economic progress.
4. The causal relationship between the value of the weight of environmental utility and decision-making will have to be clear.

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