Is Environmental Tax Effective for Total Emmission Control of Carbon Dioxide?

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Foreword

A lot of discussion is going on about the usefulness of introducing carbon tax for controlling the emission of carbon dioxide. The present paper uses a Leontief-type of input-output model to study the effects of carbon tax on the emiddion of carbon dioxide. Under the assumption of fixed gross national product, the authors come to the conclusion that the effect of carbon tax strongly depends on the tax rate and on the price of eliminating carbon dioxide. Particularly, the latter relation seems to be crucial.

Although the present Working Paper surely does not provide the final answer about the carbon tax issue, it definitely demonstrates that a system analytic approach can be very helpful in supporting the decision making about such an important topic. The reported research is part of IIASA's project Methodology of Decision Analysis.

Abstract

This paper deals with how to analyze the effectiveness of environmental tax (carbon tax) for controlling the total emission of carbon dioxide. The problem is formulated by using Leontief-type input-output model which represents a national environmental-economic model, where the environmental tax paid for emission of untreated carbon dioxide is included in the model. A numerical example based on the inter-industry table obtained in 1985, is included.

Keywords: Systems analysis; Input-output model; Global warming; Carbon dioxide; Total emission control; Environmental tax (Carbon tax)

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- Systems Analysis of Input-Output Model -

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1. INTRODUCTION

Recent increase of carbon dioxide concentration around the globe is serious and it is said that the resulting global warming may cause serious climate change and various damages in our life (IPCC, 1990a, 1990b). Therefore, we need to restrict the emission of carbon dioxide somehow.

The Government of Japan (1990) decided the Action Program to Arrest Global Warming and set a target goal of stabilizing carbon dioxide emission at 1990 level by the year 2000. The central and local governments, industries, and the public have started to act towards this end. To realize this target goal we need technological innovation to decrease carbon dioxide emission, change in people's life style (Fujita and Tamura, 1995) and value judgement (Tamura et al., 1995)

It has been discussed that carbon tax would be effective to reduce the

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emissions of carbon dioxide (Jorgenson and Wilcoxen, 1994), since the carbon tax would raise fossile fuel prices, fossile fuel demand would fall substantially, leading to a large drop in fossile fuel production. Higher fossile fuel prices would raise the cost of electricity. Consumer and firms, in turn, would demand less electricity, which will tend to reduce gross national product (GNP). Is it true? Does consumer allow to reduce GNP?

In order to answer this question we deal with a static input-output analysis of Leontief type (Leontief and Ford, 1972) including environmental tax (carbon tax) in the model. It will be shown that environmental tax is effective to decrease the total amount of carbon dioxide emission when the treatment cost of carbon dioxide becomes inexpensive. That is, good combination of technological innovation in eliminating (fixing) carbon dioxide and economic policy is effective to decrease total emission of carbon dioxide.

2. INPUT-OUTPUT ANALYSIS

Suppose there are n production sectors, and each sector produces one kind of commodity. As greenhouse gases we deal with just carbon dioxide in this paper, for simplicity.

A static input-output model of Leontief type (Tamura and Ishida, 1985, Boehm and Luptacik, 1994) including environmental tax in the model is described as

$$X_i + M_i = \sum_{j=1}^{n} x_{ij} + \sum_{j=1}^{n} y_{ij} + Z_i + F_i \tag{1}$$

$$i = 1,2,\dots,n$$

where

$$x_{ij} = a_{ij} X_j \tag{2a}$$

$$M_i = m_i X_i \tag{2b}$$

$$y_{ij} = d_{ij}\alpha_j p_j \tag{2c}$$

$$Z_i = t(1-\alpha_i)p_i \tag{2d}$$

$$p_i = h_i E_i \tag{2e}$$

$$h_i = g_1\beta_i^1 + g_2\beta_i^2 + g_3\beta_i^3 + g_4\beta_i^4 \tag{2f}$$

$$\beta_i^1 + \beta_i^2 + \beta_i^3 + \beta_i^4 = 1$$

$$E_i = \gamma_i X_i \tag{2g}$$

$$i, j = 1, 2, \ldots, n$$

X_i: total output of commodity i produced by sector i

M_i: import of commodity i from outside

x_{ij}: economic input of commodity i for industrial production at sector j

y_{ij}: economic input of commodity i for eliminating carbon dioxide at sector j

Z_i: environmental tax paid in kind (commodity i) imposed on carbon dioxide emitted from sector i

F_i: final demand of commodity i

a_{ij}: input-output coefficient showing economic input of commodity i per unit level of industrial production at sector j

m_i: import coefficient of commodity i showing import of commodity i per unit level of industrial production at sector j

d_{ij}: marginal input coefficient for eliminating carbon dioxide showing economic input of commodity i per unit level of eliminating carbon dioxide at sector j

α_j: elimination rate of carbon dioxide at sector j

p_j: generation of carbon dioxide at sector j

t: environmental tax coefficient showing environmental tax imposed on per unit level of carbon dioxide emission

E_i: primary energy consumed at sector i

h_i: generating coefficient of carbon dioxide for consuming primal energy at sector i

g_1, g_2, g_3, g_4: generating coefficients of carbon dioxide for consuming coal, oil, natural gas and nuclear energy, respectively

β_i^1, β_i^2, β_i^3, β_i^4 : ratio of consuming coal, oil, natural gas and nuclear energy at sector i

γ_i: energy consumed per unit level of industrial production at sector i

Substituting eqn. (2) into eqn. (1) and using vector-matrix notation, we obtain

$$X = AX + \{D[\alpha] + T(I - [\alpha])\}H\Gamma X + F - MX \tag{3}$$

where

$$X = \mathrm{col}\,(X_1, X_2, \ldots, X_n)$$

$$A = \begin{bmatrix} a_{11} a_{12} \ldots a_{1n} \\ a_{21} a_{22} \ldots a_{2n} \\ \vdots \quad \vdots \quad \vdots \\ a_{n1} a_{n2} \ldots a_{nn} \end{bmatrix}, \qquad D = \begin{bmatrix} d_{11} d_{12} \ldots d_{1n} \\ d_{21} d_{22} \ldots d_{2n} \\ \vdots \quad \vdots \quad \vdots \\ d_{n1} d_{n2} \ldots d_{nn} \end{bmatrix}$$

$$T = \mathrm{diag}\,(t, t, \ldots, t), \qquad \Gamma = \mathrm{diag}\,(\gamma_1, \gamma_2, \ldots, \gamma_n)$$

$$F = \mathrm{col}\,(F_1, F_2, \ldots, F_n)$$

$$M = \mathrm{diag}\,(m_1, m_2, \ldots, m_n), \qquad [\alpha] = \mathrm{diag}\,(\alpha_1, \alpha_2, \ldots, \alpha_n)$$

$$H = \mathrm{diag}\,(h_1, h_2, \ldots, h_n)$$

Notation diag(*,*,...,*) denotes $n \times n$ diagonal matrix and notation col(*,*,...,*) denotes n dimensional column vector. Solving eqn. (3) with respect to X we obtain

$$X = \left[I - A + M - \{D[\alpha] + T(I - [\alpha])\}H\Gamma\right]^{-1} F \tag{4}$$

In this economic system total emission of carbon dioxide and total consumption of primary energy are described as

$$P = \sum_{j=1}^{n} (1 - \alpha_j)\, h_j E_j + p_c \tag{5}$$

Table 1 Input-Output Table

Into / From	Sector 1		···	Sector n		Final Demand	Import	Total Output	Total Energy
	Prod	Elim	···	Prod	Elim				
Sector 1	x_{11}	y_{11}	···	x_{1n}	y_{1n}	F_1	M_1	X_1	E_1
Sector 2	x_{21}	y_{21}	···	x_{2n}	y_{2n}	F_2	M_2	X_2	E_2
⋮	⋮	⋮	⋮		⋮	⋮	⋮	⋮	⋮
Sector n	x_{n1}	y_{n1}	···	x_{nn}	y_{nn}	F_n	M_n	X_n	E_n
Pollution	Emi	Elim	···	Emi	Elim	Emi	Total Emission		
	p_1	$\alpha_1 p_1$	···	p_n	$\alpha_n p_n$	p_c	P		
Tax	Z_1		···	Z_n					

Prod : Production, Elim : Elimination, Emi : Emission

$$E = \sum_{j=1}^{n} \gamma_j X_j + e_c = \sum_{j=1}^{n} E_j + e_c \tag{6}$$

where

p_c: carbon dioxide emission from the final demand (consumer) section

e_c: energy consumption at the final demand (consumer) section

Table 1 shows the input-output table which shows the data used for analyzing input-output model.

3. NONLINEARITY BETWEEN ELIMINATION RATE OF CARBON DIOXIDE AND COST OF ELIMINATION

Although the technology of eliminating (or fixing) carbon dioxide is poor at the moment, it is easily recognized that there exists a highly nonlinear relation between the elimination rate of carbon dioxide and the cost of elimination. We take into account this nonlinearity in our input-output model as follows:

Suppose

$$d_{ij} = \eta\, d_{ij}^0 \tag{7a}$$

$$\alpha_j = f_j(\eta)\, \alpha_j^0 \tag{7b}$$

where

d_{ij}^0: marginal input coefficient for eliminating carbon dioxide at the time when the input-output table was obtained

α_j^0: elimination rate of carbon dioxide at sector j at the time when the input-output table was obtained

$f_j(\eta)$: multiplier coefficient for α_j^0 as a function of η

Equation (7) implies that if the input of commodities for carbon dioxide elimination was multiplied by η, the elimination rate of carbon dioxide would be multiplied by $f_j(\eta)$.

Suppose $f_j(\eta)$ is written as

$$f_j(\eta) = \eta / \left\{ 1 + \alpha_j^0 (\eta - 1) \right\} \tag{8}$$

then, from eqns. (7) and (8), we obtain the properties as follows:

1) $\alpha_j = 0$ if $\eta = 0$

2) $\alpha_j = \alpha_j^0$ if $\eta = 1$

3) $\alpha_j \rightarrow 1$ if $\eta \rightarrow \infty$

We postulate that each production sector j minimizes the sum of environmental tax to be paid and the cost of eliminating carbon dioxide where it is assumed that $d_{ij} = 0,$ for $i \neq j$, that is

$$\underset{\alpha_j}{\text{minimize}} \left\{ t \left(1 - \alpha_j\right) + d_{jj}\, \alpha_j \right\} p_j \tag{9}$$

From eqns. (7)-(9) we obtain

$$\alpha_j = 1 - \sqrt{\frac{d_{jj}^0 \left(1 - \alpha_j^0\right)}{\alpha_j^0\, t + d_{jj}^0 \left(1 - \alpha_j^0\right)}} \tag{10}$$

This implies that the following reasonable properties hold between environmental tax t and elimination rate α_j .

1) $\alpha_j = 0$ if $t = 0$

2) $\alpha_j \rightarrow 1$ if $t \rightarrow \infty$

4. NUMERICAL EXAMPLE

Input-output table (General Affairs Agency, 1989) obtained in 1985 with 13 sectors, is aggregated to 4 sectors as shown in **Table 2**, where each sector includes following items:

Sector 1: Agriculture, mining and construction

Sector 2: Manufacturing

Sector 3: Transportation

Sector 4: Public and others

Since carbon dioxide elimination was not performed in 1985, it is assumed that the elimination rate of carbon dioxide in each sector was

$\alpha_i^0 = 0.01, \quad i = 1,2,3,4$

Taking into account eqn. (7) and Table 2, we obtain

$[\alpha] = \text{diag}\left(f(\eta)\,\alpha_1^0,\ f(\eta)\,\alpha_2^0,\ f(\eta)\,\alpha_3^0,\ f(\eta)\,\alpha_4^0\right)$

$$A = \begin{bmatrix} 0.0413 & 0.341 & 0.00446 & 0.0662 \\ 0.0816 & 0.429 & 0.0350 & 0.0823 \\ 0.127 & 0.218 & 0.103 & 0.216 \\ 0.0344 & 0.125 & 0.0214 & 0.156 \end{bmatrix}$$

Table 2 Input-Output Table in 1985(4 sectors)

Into / From	Sector 1 Prod	Sector 2 Prod	Sector 3 Prod	Sector 4 Prod	Final Demand	Import	Total Output
Sector 1	3,122,771	25,835,573	337,412	5,010,359	55,383,251	17,095,917	75,689,145
Sector 2	23,883,399	125,563,067	8,930,034	24,074,956	122,794,385	15,372,591	292,618,149
Sector 3	4,472,352	7,646,068	3,615,881	7,588,293	13,003,881	1,700,175	35,114,398
Sector 4	8,771,283	31,952,932	5,452,948	39,768,147	169,937,200	3,447,541	254,638,114

unit : million yen

$M = \text{diag}(0.226,\ 0.0525,\ 0.0484,\ 0.0135)$

$F = \text{col}\left(5.54\times10^7,\ 1.23\times10^8,\ 1.30\times10^7,\ 1.70\times10^8\right)$ (million yen)

Marginal input coefficients for eliminating carbon dioxide is estimated from Environment White Paper (Environment Agency 1992) as

$D = \eta D^0$

$D^0 = \text{diag}(3,\ \ 3,\ \ 3,\ \ 3)\times10^{-5}$

Generating coefficients of carbon dioxide for consuming coal, oil, natural gas and nuclear energy are assumed as

$g_1 = 1018.8,\quad g_2 = 784.3,\quad g_3 = 571.5,\quad g_4 = 0\ \left(\text{kg}/10^{10}\text{cal}\right)$

Ratio of consuming coal, oil, natural gas and nuclear energy in each sector is assumed as follows:

Sector 1: $\beta_1^1 = 0.007,\quad \beta_1^2 = 0.981,\quad \beta_1^3 = 0.000,\quad \beta_1^4 = 0.012$

Sector 2: $\beta_2^1 = 0.363,\quad \beta_2^2 = 0.503,\quad \beta_2^3 = 0.068,\quad \beta_2^4 = 0.066$

Sector 3: $\beta_3^1 = 0.004,\quad \beta_3^2 = 0.984,\quad \beta_3^3 = 0.005,\quad \beta_3^4 = 0.007$

Sector 4: $\beta_4^1 = 0.104,\quad \beta_4^2 = 0.639,\quad \beta_4^3 = 0.149,\quad \beta_4^4 = 0.108$

Energy consumed per unit level of industrial production in each sector is assumed as

$\Gamma = \text{diag}(0.176,\ \ 0.418,\ \ 1.677,\ \ 0.111)\ \ (10^{10}\text{cal/million yen})$

From eqn. (10) we could assess the elimination rate α with respect to environmental tax coefficient t as shown in **Fig. 1**. Then, we could assess total output X_i in each sector and total emission of carbon dioxide P with respect to environmental tax coefficient t as shown in **Figs. 2** and **3**, respectively.

Figure 3 shows that for larger environmental tax t we get larger total emission of carbon dioxide. This is because the cost of eliminating carbon dioxide is too high, that is, too much economic input of commodity per unit level of eliminating carbon dioxide is necessary, and as the result, excessive carbon dioxide is generated. In this case each sector would like to pay environmental tax rather than to make efforts to eliminate carbon dioxide. This implies that under poor technology of eliminating carbon dioxide, environmental tax (carbon tax) is not effective to decrease the total emission of carbon dioxide.

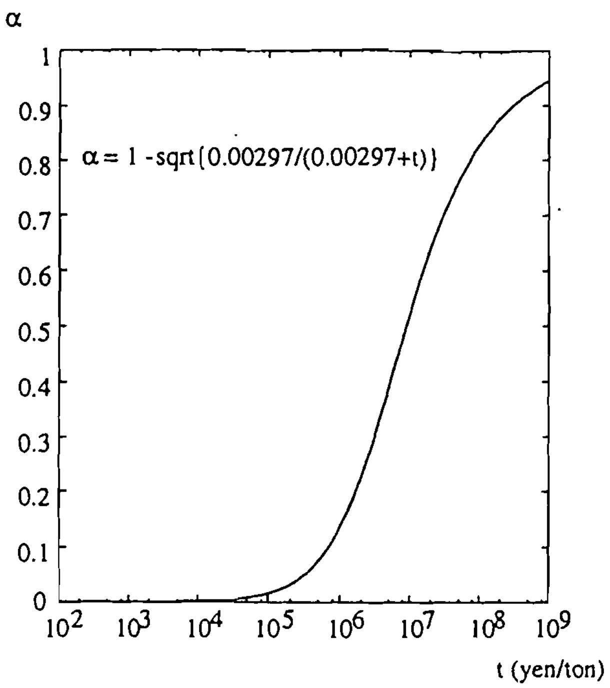

Fig. 1 Relationship between the environmental tax rate t and the removal rate α of CO_2 at present

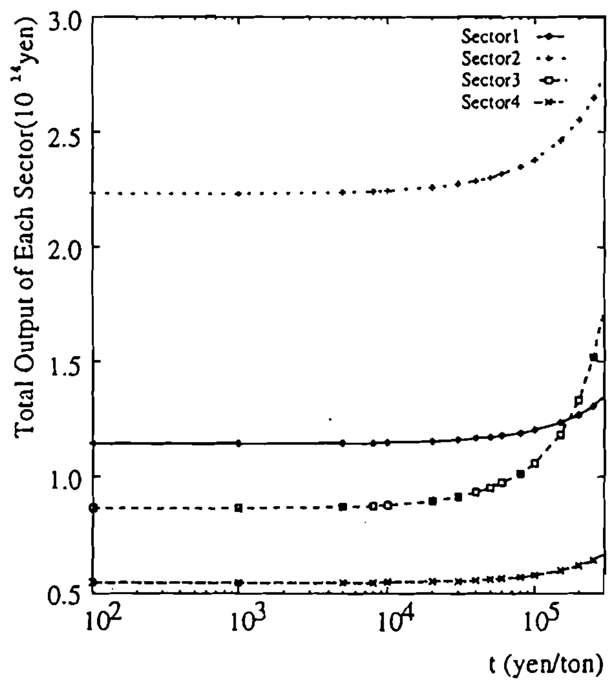

Fig. 2 Relationship between the environmental tax rate t and the total output of each sector at present

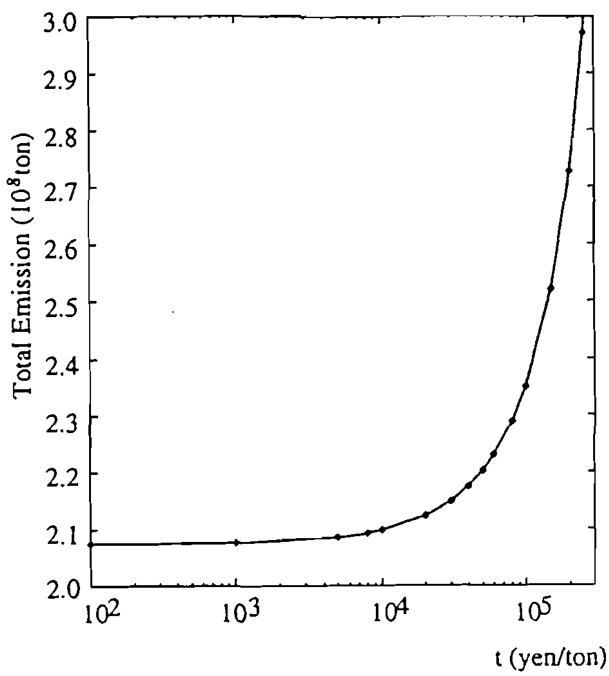

Fig. 3 Relationship between the environmental tax rate t and the total emission of CO_2 at present

Suppose, as the result of technology innovation, the cost of eliminating carbon dioxide would be reduced to 1/10, and let

$D^0 = \mathrm{diag}(3,\ 3,\ 3,\ 3) \times 10^{-6}$ (million yen/kg)

Figure 4 shows the relationship between the elimination rate α and environmental tax coefficient t under higher technology of eliminating carbon dioxide with low cost. **Figures 5** and **6** shows total output X_i and total emission of carbon dioxide P with respect to environmental tax t under higher technology of eliminating carbon dioxide with low cost.

If the cost of eliminating carbon dioxide would be low, it is less expensive to eliminate carbon dioxide compared with paying environmental tax for untreated carbon dioxide emission. At about t=80,000yen/ton the total emission of carbon dioxide is minimized in this numerical example. The elimination rate of carbon dioxide is 0.112 in each sector.

If the environmental tax t would exceed 80,000yen/ton, the total output would increase rapidly because of the nonlinear relationship between the

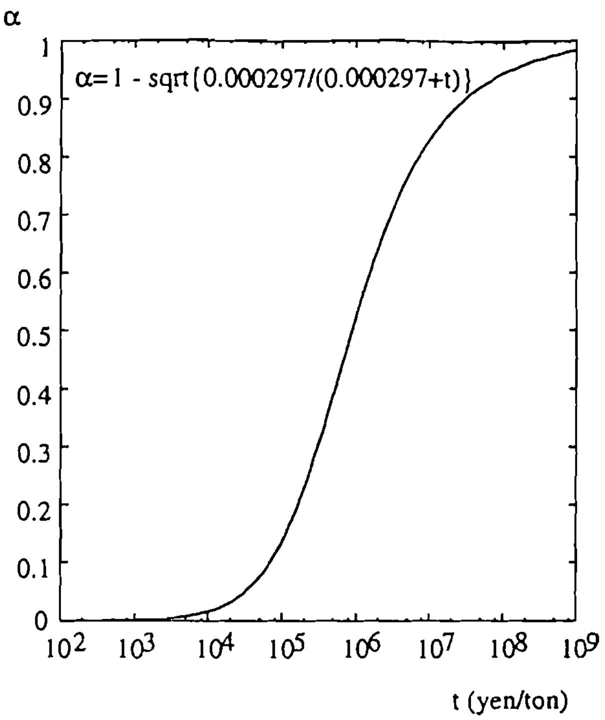

Fig. 4 Relationship between the environmental tax rate t and the removal rate α of CO_2 in future

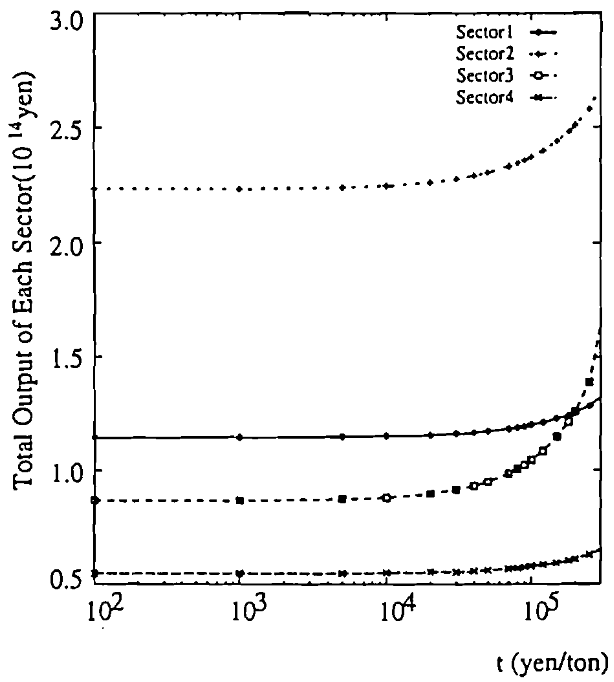

Fig. 5 Relationship between the environmental tax rate t and the total output of each sector in future

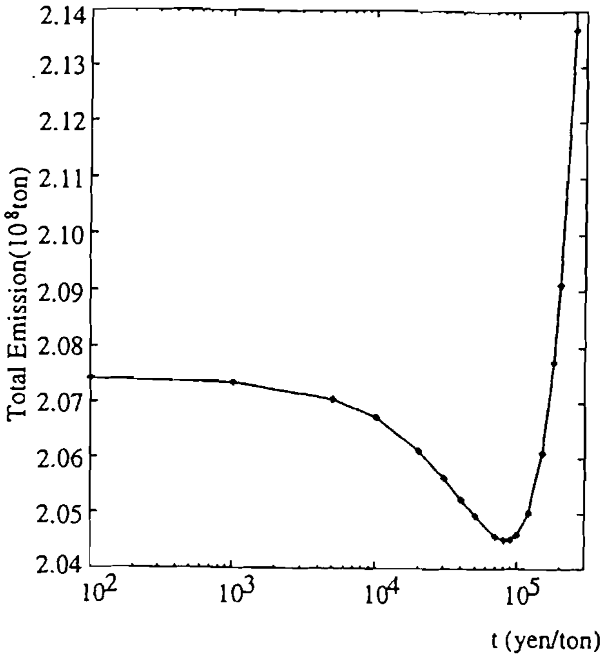

Fig. 6 Relationship between the environmental tax rate
t and the total emission of CO_2 in future

elimination rate of carbon dioxide and cost of elimination. As the result, the total emission of carbon dioxide would increase rapidly. This implies that under high technology of eliminating (fixing) carbon dioxide with low cost, environmental tax (carbon tax) is quite effective to decrease the total emission of carbon dioxide, however, too high tax rate would again increase the total emission.

5. CONCLUSION

In this paper, under the assumption that

1) consumer would not allow to reduce economic consumption level (gross national product),
2) environmental tax is paid in kind (commodity),
3) each production sector minimizes the sum of environmental tax to be paid

for untreated carbon dioxide and the cost of eliminating (fixing) carbon dioxide, and
4) there exists nonlinear relationship between the elimination rate of carbon dioxide and the cost of elimination,
we have shown how to evaluate the effectiveness of environmental tax for controlling the total emission of carbon dioxide.

Numerical example, based on the inter-industry table obtained in 1985, shows that
1) under poor technology of eliminating carbon dioxide with high cost, environmental tax would not be effective to decrease the total amount of carbon dioxide emission, but
2) after developing high technology of eliminating carbon dioxide with low cost, environmetal tax would become quite effective to decrease the total amount of carbon dioxide emission, and there exists optimum tax level to minimize the total amount.

For further research with this direction we need to develop
1) primal and dual models to deal with commodity flow and cash flow, respectively (Lowe, 1979),
2) dynamic model of analyzing the effectiveness of environmental tax for various scenarios of economic and environmental policies.

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