2.5 AN ENERGY/ECONOMY MODEL FOR THE EVALUATION OF ENERGY TECHNOLOGIES AND POLICY OPTIONS IN JAPAN

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ABSTRACT

An econometric simulation model for the evaluation of energy and environmental options is described. This model is designed to generate the dynamic behavior of energy and economic activities along with the energy price changes. The author exhibits the structure and simulation results under various future scenarios on oil supply crisis, carbon emission tax and cogeneration systems. The future uncertainties and correlations among them are evaluated by the cross impact method. The main results are the followings: (1)carbon emission tax can stabilize the carbon emission level at that of 1990 level, (2)GDP loss by the tax is calculated to be 400,000-500,000 yen per carbon ton reduction, and (3)the economic loss by oil supply crisis is strongly influenced by the supply price elasticity.

INTRODUCTION

Nowadays, traditional energy systems face various kinds of problems: the global and local environmental issues, supply uncertainties, etc., while the new energy options such as cogeneration systems, tax and subsidies are discussed for the next generation. However, the macro effects of these technological and institutional options are not yet clear. It is one of the reason why many Energy/Economy/Environmental models are developed in these years (Nordhaus (1991)). For example, Edmonds and Reilly (1983) have developed a global simulation model dividing the world into nine regions. A.Mann *et.al* (1991) present global economy and environmental scenarios until 2100 based on the GLOBAL-2100 model. Yamaji *et.al.* (1991) have eagerly investigated the possibility and problems of the carbon emission trade and taxation and subsidy systems to reduce carbon emission in Japan.

Many of these studies employ the equilibrium models which are powerful to provide the detailed economic informations. On the other hand, they are not always appropriate to evaluate the transient behavior of energy and economic activities since they are basically static or quasi-static models. Dynamic simulation models have advantage to see the dynamic phenomena.

The model described in this paper is a dynamic simulation model to investigate the dynamic behaviors of Japanese energy and economy system under various supply and demand scenarios. Cross impact method (Mori (1989)) has been applied to extract the likely scenarios from the future uncertain interactions among political and technological events.

1. STRUCTURE OF THE MODEL

The skeleton of the model is shown in Figure.1. The model contains five types of primary energy sources: oil, LPG, coal, LNG, hydropower and nuclear power generation. These are transformed into nine secondary energies: heavy oil, kerosene, gas, light oil, gasoline, jet fuel, coke, naphtha and electricity. Final demand sectors are three: transportation, industry and public sector which involves services and households. The end use of the industry sector and the public sector involves thermal use and electricity consumption.

The electric power supply sector consists of three parts: thermal power generations, cogeneration systems and non-fossil fuel generations involving hydropower and nuclear power.

Economic activity block is indispensable to analyze the interactions between energy flow and economics. It is, however, quite difficult to represent the mechanism of the domestic and international economic activities in the dynamic model. The author imposes an ad hoc economic equation.

In the thermal energy use of the industry sector and the public sector, multi-logit model is employed to evaluate the interfuel substitutions corresponding to the relative price changes. The average energy price is also obtained when the multi-logit model calculates the input fractions of fossil fuels. It determines the total energy demand through the demand functions. Hence the model provides the demand for each energy source.

The followings are the procedure to evaluate the economic loss caused by the energy resource supply reduction: When the supply capacity of primary energy resource declines, energy prices escalate until the results of inter fuel substitution and demand adjustment are compatible with supply capacity. On the other hand, the supply capacity may increase corresponding to the price escalation. In the model, the above procedure is treated by a shift of supply function as is shown in Figure.2.

Let D(P) denote the demand at price P. When the price goes up from P to P', then the loss of consumer's surplus appears as $\int_P^{P'} D(p)dp$. The author employs it as an index of the economic loss caused by the supply crisis. It should be noted that the above procedure is not directly applicable to the model since the final demand is not a direct function of the primary energy prices. The procedure to calculate the consumer's surplus loss is shown in Figure.3.

Since Japan imports most of fossil fuel resources, it is assumed that the producer's surplus loss does not affect the domestic economy.

2. EQUATIONS OF THE MODEL

2.1 Energy Final Demand Equations

The basic form of the demand function is as follows:

$$\ln D_t = \alpha \ln D_{t-1} + \beta \ln Y_t + \gamma \ln P_t + C \qquad (1)$$

where D, Y and P denote demand, real GDP and real price, respectively. In the cases of coke and naphtha, the output indexes of the iron and steel industry and the chemical industry are employed instead of GDP. The estimated parameters are summarized in the Table.1.

2.2 Inter-fuel Substitution Model

The multi-logit model is employed to represent the inter fuel substitution for the industry, power generation and public thermal use. That is,

$$S_{i,t}=\frac{A_i\exp(\alpha_i P_{i,t})S_{i,t-1}^{\beta}}{\Sigma A_k\exp(\alpha_k P_{k,t})S_{k,t-1}^{\beta}} \qquad (2)$$

where Si,t and Pi,t denote the input fraction and the price of i-th energy type at period t, respectively. In the model, natural logarithm of real price is used for Pi,t.
The estimated parameters are shown in the Table.2. The theoretical and the historical energy input share for the industry and the electric generation thermal use are shown in Figure.4 and Figure.5.

2.3 Electric Power Generation Block

The electric power generation block determines the price of electricity and the nuclear and hydropower generation capacity. Here the latter is given exogenously. The price of electricity is determined by the simple historical relation. That is,

$$\ln Pe = .314*\ln P_f + .0355*year + .0591 \qquad (3)$$
$$(5.94) \qquad (7.86) \qquad (.149)$$
$$R^2 = .960 \quad D.W = 1.72$$

where P_e and P_f denote the price of electricity and average price of fossil fuel input for the thermal generation, respectively.

2.4 Interrelations among Fossil Fuel Prices

In the case of short term oil supply reduction, there could be interrelations among the price escalation patterns of fossil fuel products. Here, The natural logarithm of the price of each fossil fuel product is regressed on the natural logarithm of the heavy oil price. Table.3 exhibits the estimation results. Thus it is assumed that the prices of LNG, LPG and other oil products change along with the equations when oil supply crisis occur. Coal supply crisis and LNG supply crisis are excluded in this study.

2.5 Economic Activity Block

The economic activity block is needed to estimate the macro effects of the technological and institutional options. The existing studies often divide the energy/economic system into two blocks, i.e., an energy flow model and a multi sector equilibrium model (Mann *et al* (1991), Yamaji *et al* (1991)). On the contrary, Edmonds and Reilly employed a simplified relationship between economic activity and the price of energy services, say PS, as follows:

$$GNP=GNP_0 \cdot PS^{r \cdot y} \qquad (4)$$

where GNP_0 and GNP denote potential GNP and actual GNP, respectively. 'r' and 'y' represent parameters (Edmons *et al* (1983)). Demand for each energy source is defined as a function of Y.
In this study, the author employs the following dynamic extension of the equation (4) for the sake of simplicity rather than theoretical basis.

$$Y_t=\alpha\ln Y_{t-1} + \beta_0\ln PS_t + \beta_1\ln PS_{t-1} + \gamma_0\ln PL_t + \gamma_1\ln PL_{t-1}$$
$$+\theta t + \delta_0\ln x_t + \delta_1\ln x_{t-1} + C \qquad (5)$$

where Y, PL and x denote GDP, wage and exchange rate (yen per U.S.dollar), respectively. The parameters are estimated on the historical data. The price of heavy oil, say PH, is used as a proxy for the PS. The estimated results are the followings:

α=0.319	β_0=-.0580	β_1=.0185	γ_0=.364	γ_1=-.116
θ=.017	δ_0=0	δ_1=.140	C=1.26	

The estimation procedure of the above is shown in the Appendix.

2.6 Cogeneration Systems

Cogeneration systems are often regarded as a key factor of the future energy systems. Here, the followings are assumed.

(1)The capacity utilization rate, energy efficiency and electric power generation efficiency are 50%, 80% and 40% respectively according to the fuel cell systems.

(2)All the electricity and the thermal energy from cogeneration systems are used by the public sector.

(3)The cogeneration capacity in the reference case is 5GW in 2000 and 15GW in 2020.

3. FUTURE SCENARIO GENERATION UNDER UNCERTAINTIES BY X-I METHOD

There are many uncertain issues in the future energy systems. It should be noted that these could occur independently. Therefore traditional Monte-Carlo simulation method may fail to give the appropriate future information. In this paper, cross impact method (X-I method) (Mori (1989)) is employed to treat the interdependencies among future uncertain factors. It provides the ranking of the possible future scenarios based on the subjective occurrence probabilities given by the decision maker.

Here, the following four events are selected for the key factors: (A)oil supply crisis, (B)carbon emission tax, (C)strong regulation on nuclear power generation and (D)promotion of cogeneration systems. The experts on energy issues give the subjective probabilities for the year 2000 as is shown in Table.4. The data is modified following to the procedure of the X-I method. The results are exhibited in Table.5. The calculated ranking results are summarized in Table.6, where the minimum, maximum and entropy maximum four dimension probabilities are presented. It is noteworthy that the scenario (14)-(1011) gives the higher score than the scenario (10)-(1001), although the occurrence probability of the third event is 0.5. Here the scenario (14) is employed for the simulation, say X-I case.

4. SIMULATION

4.1 Simulation Scenario Settings

The parameters for the reference case are determined by the following way: The author assumed the base annual GDP growth rate to be 3.5% until 2000 and 3.0% after that. Thus the coefficient θ of the equation (5) is set to be 1.703%/year until 2000 and 1.192%/year after that. The annual growth rate of nuclear and hydropower generation is set to be 3.45%.

It is important from the view of energy security to evaluate the outcomes of the oil supply crisis and carbon emission tax in spite of their low probabilities. For the former, it is assumed that the oil supply function shifts 15,000Ml/year for the period from 1995 to 1996, which is about seven percent of total crude oil import of Japan in 1990. Here the price elasticity of the supply function is a key parameter. The author assumes two cases, say 0.0 (supply crisis case-1) and 0.3 (supply crisis case-2). In the X-I scenario, 0.1 price

elasticity is assumed. The total amount of consumer's surplus loss is calculated to evaluate the economic effects of the oil supply crisis. The author assumed the following taxation scenario: 4000¥/C-t carbon tax is imposed on the fossil fuels in 1993 and then increases annually 2000¥/C-t after that. The sensitivity analysis of the tax is discussed further in the section 4.3.

In case of nuclear power regulation, the annual growth rate of non-thermal electric power generation is set to be 2.0%. The capacity of cogeneration is doubled for the cogeneration promotion case. The scenario parameters are summarized in the Table.7.

4.2 Simulation Results

Because of the page restriction, only some part of simulation results can be shown in this paper.

Figure.6 and Figure.7 exhibit the simulation results in terms of the changes of the total carbon emission. Figure.8 shows the behaviors of the consumer's surplus loss in the cases of oil supply crisis.

The main findings of the simulation results are the followings:

(1).The implementation of cogeneration systems contributes around 0.96C-t to 0.99C-t carbon emission reduction per 1KW cogeneration capacity at 50% capacity utilization rate.

(2).The economic recession caused by the oil supply crisis is recovered quickly. The loss of consumer's surplus, however, remains until 2010 as is shown in the Figure.11. The average loss, that is, total amount of consumer's surplus loss divided by 25 years and by 30,000Ml, comes to 96.6¥/l in the case of 0 supply price elasticity while 32.1¥/l in the case of 0.3 supply price elasticity. Therefore it is concluded that the potential supply capability of oil substitution energy sources contribute the energy security even if they have no marketability at the moment.

(3).The carbon emission tax may stabilize or reduce the carbon emission, but it is quite expensive. The detailed analysis is discussed in the following section.

4.3 Sensitivity Analysis of Carbon Emission Tax

In order to clarify the macro economic effects of carbon emission taxation systems, sensitivity analysis is achieved varying the escalation tax value from 400¥/C-t to 4000¥/C-t. The initial tax is set to be 4000¥/C-t in 1993.

The simulation results on the total carbon emission, carbon emission of each sector, i.e., industry sector, electric generation sector, public and household sector and transportation sector, are exhibited in the Figure.9 to Figure.13. Total carbon emission can be stabilized at that of the 1990's level by 1000¥/C-t annual increasing tax. One can see the difficulty of reducing carbon emission of the transportation sector.

Figure.14 exhibits the average GDP loss per carbon ton emission reduction. It is shown that the cost of carbon emission comes to around 400,000¥/C-t to 500,000¥/C-t. It is basically similar to the results by Yamaji (1991). One can conclude that it is not a preferable strategy to reduce the carbon emission by taxation only while the above cost is almost same to the KW unit initial cost of cogeneration system (Ishikawa (1990)). The policy maker should consider the mixed strategy, taxation with subsidies for the efficient energy systems.

ACKNOWLEDGEMENT

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APPENDIX

The parameters of the equation (5) are estimated by the following procedure. At first, the domestic demand (DD) is regressed by the heavy oil price(PH), wage(PL) and year.

$$\ln DD = -.058*\ln PH + .364*\log PL + .0250*year + 5.53 \qquad \text{(A-1)}$$

(2.77) (3.45) (6.28) (29.2)

R2=.986 D.W.=.997

The wage PL is formulated as follows:

$$PL = .741*\ln PL(-1) + .154*\ln Y(-1) - .585 \qquad \text{(A-2)}$$

(16.8) (3.39) (2.76)

R2=.998 D.W.=2.39

The ratio of Y to DD is

$$\ln(Y/DD) = .319*\ln(Y/DD)(-1) + .140*\ln(¥/\$)(-1) - 2.51 \qquad \text{(A-3)}$$

(8.91) (5.00) (7.44)

R2=.871 D.W = 1.50

where (¥/$) denotes exchange rate. Inserting (A-1) into (A-3), one obtains the equation (5).

Finally, the exchange rate is calculated by the following equation.

$$\ln(¥/\$) = .816*\ln(¥/\$)(-1) - 1.78*\ln(Y/DD)(-1) + .924 \qquad \text{(A-4)}$$

(5.60) (1.90) (1.17)

R2=.829 D.W = 1.62

One can interpret the equation (A-4) that the exchange rate converges at 150.8¥/$ when the trade revenue and expenditure are balanced.

The above equations exhibit appropriate parameters and preferable fittings, as is shown in the Figure A-1 to A-3. However, since the above formulation is quite ad hoc and lacks theoretical basis, this block represents no more than historical trends.

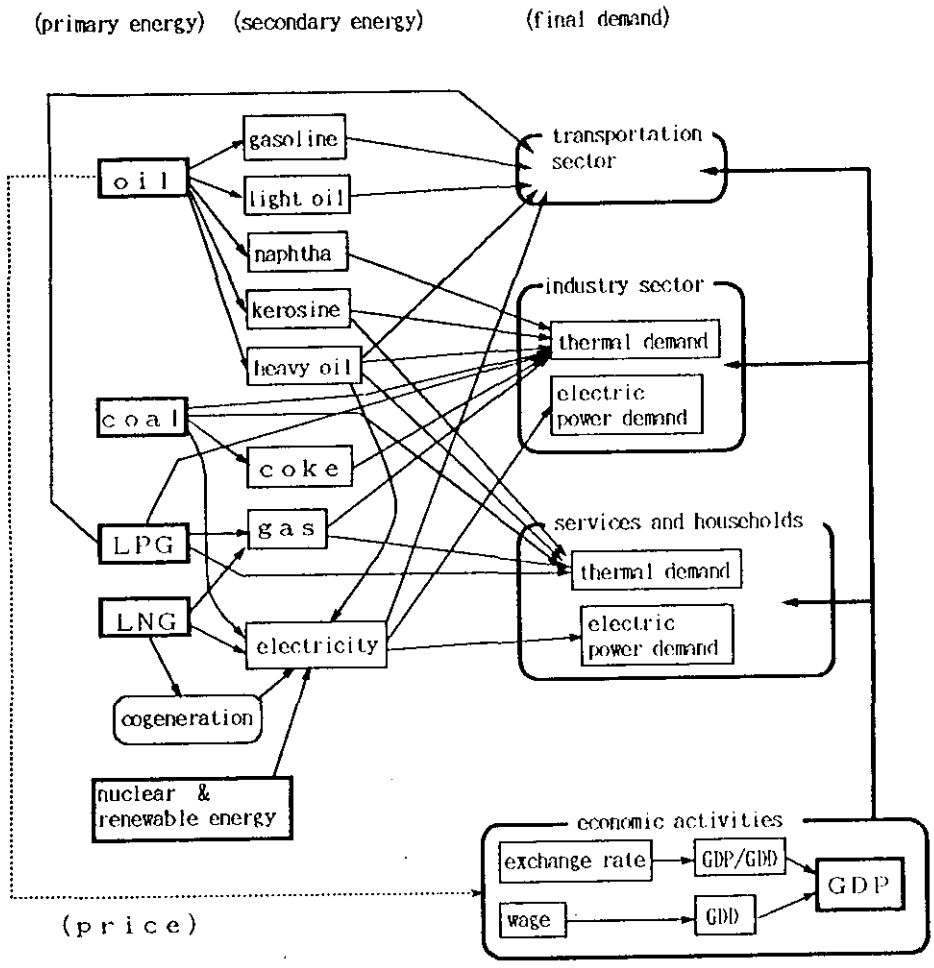

Figure 1 Structure of the energy flow model

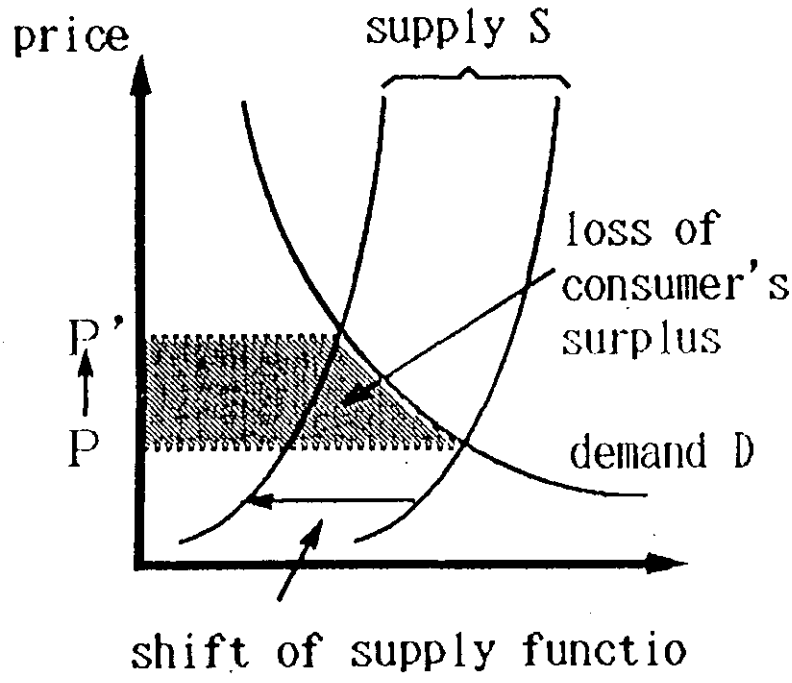

Figure 2 Supply function shift and the loss of consumers' surplus

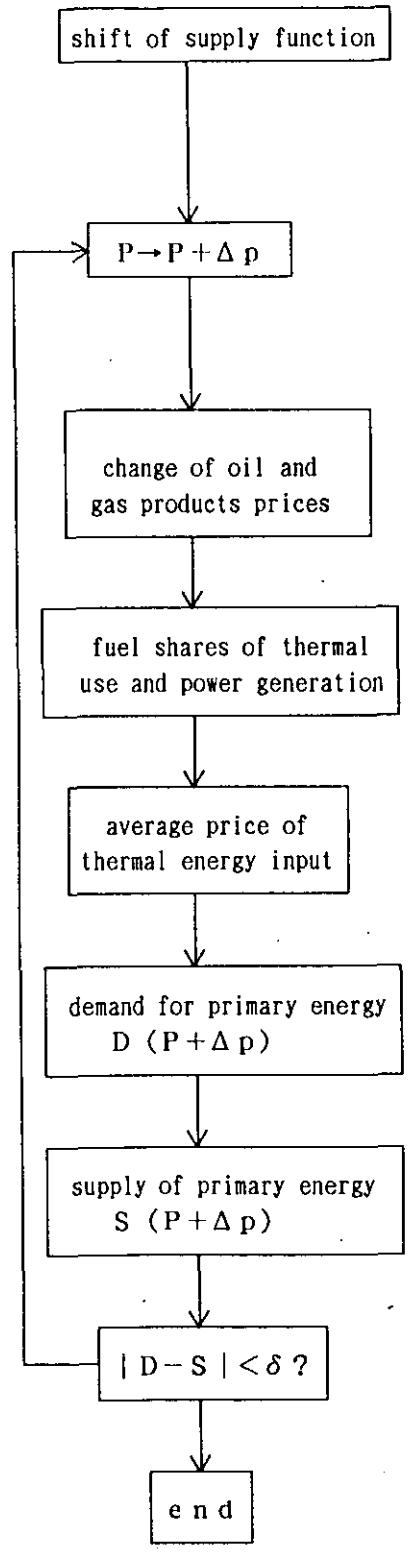

Figure 3 Procedure for the equilibrium between supply and demand under supply reduction

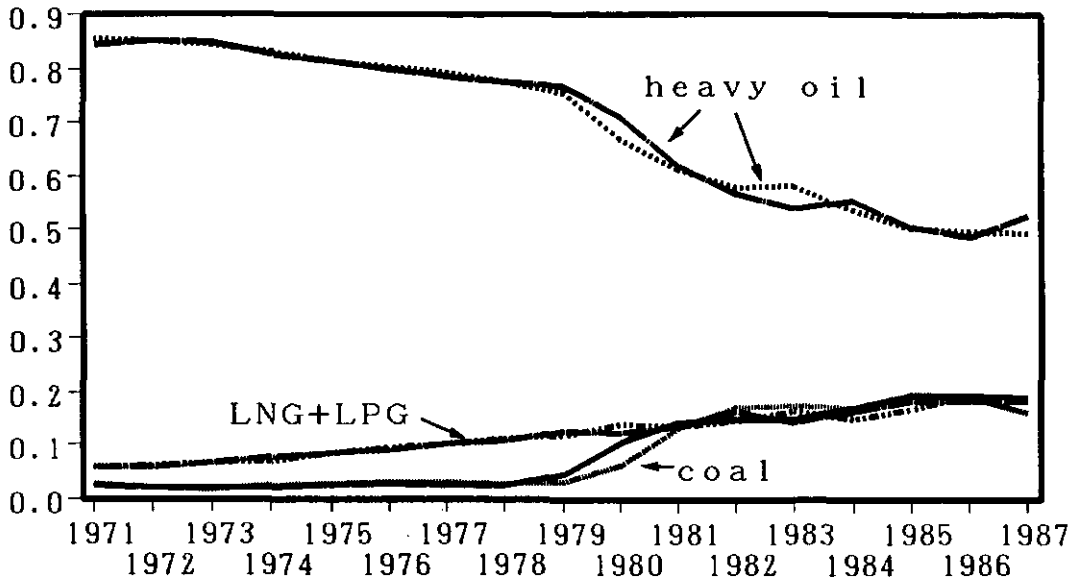

Figure 4 Historical and theoretical fossil fuel demand share values for industrial sector
(solid line; historical value , broken line: theoretical value)

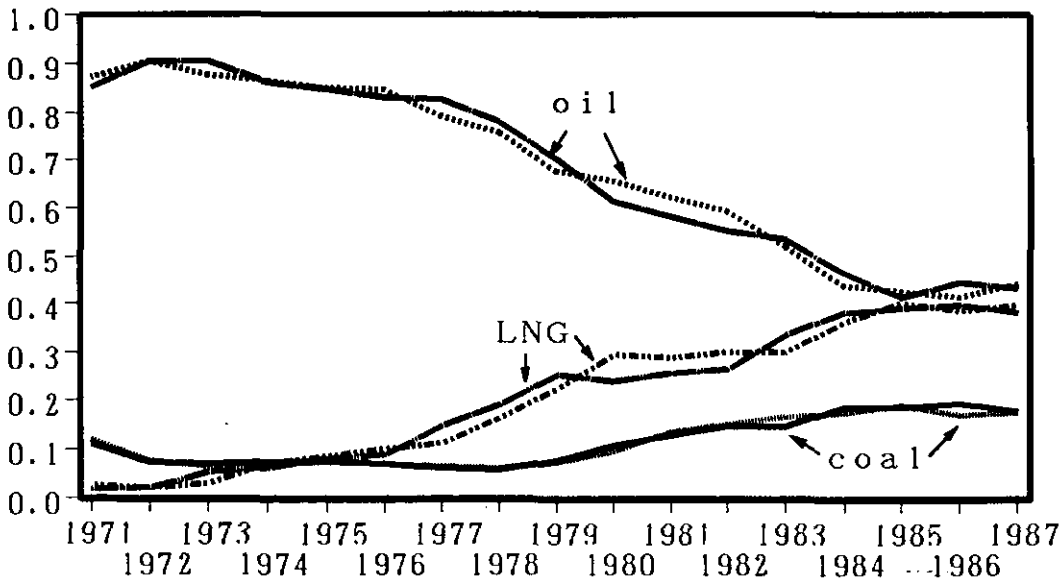

Figure 5 Historical and theoretical fossil fuel demand share values for electric power generation sector
(solid line; historical value , broken line: theoretical value)

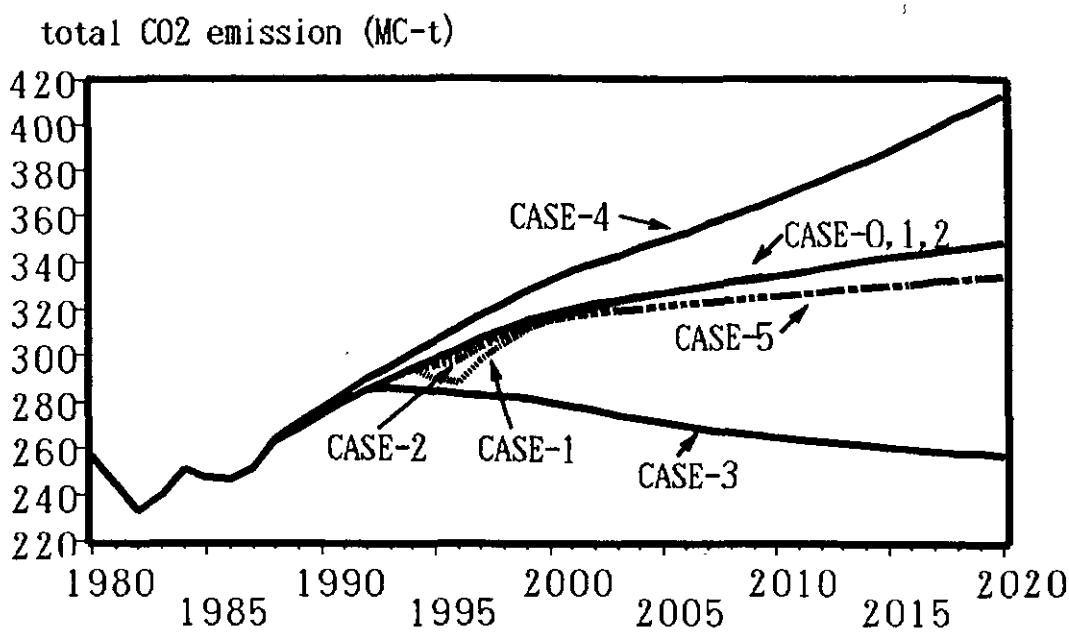

Figure 6 Simulation results: total CO2 emission (MC-t)
CASE-0 to CASE-5

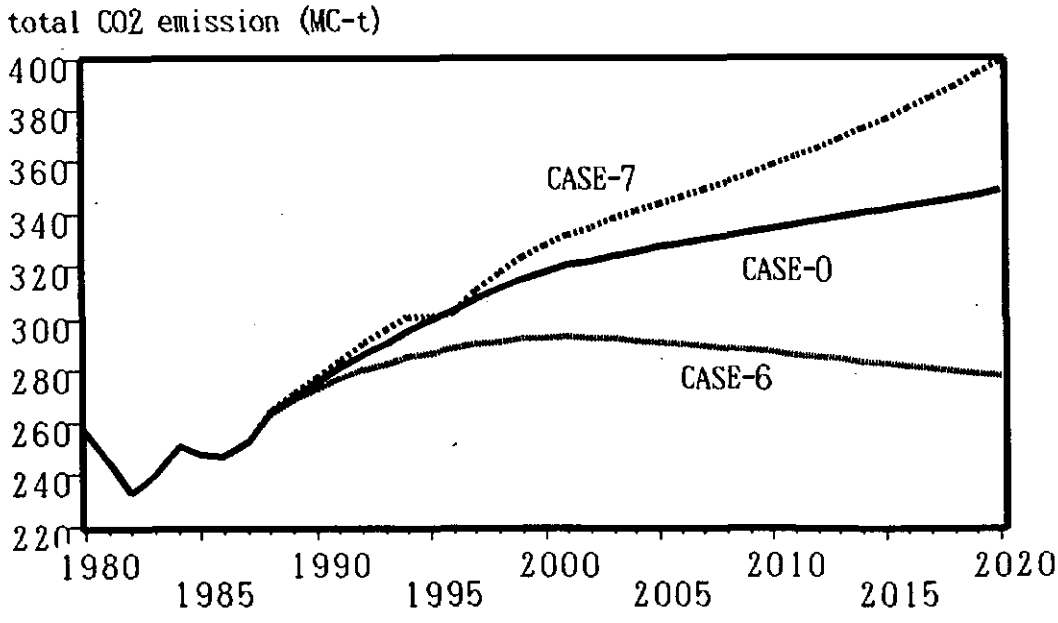

Figure 7 Simulation results: total CO2 emission (MC-t)
CASE-0, CASE-6 and CASE-7

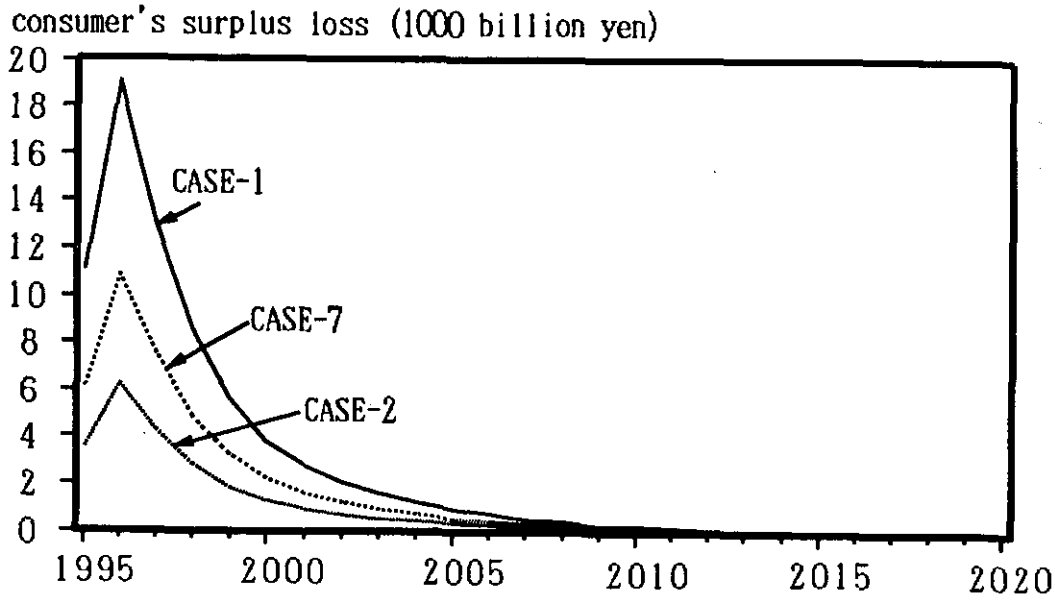

Figure 8 Consumer's surplus loss changes in case of oil supply crisis

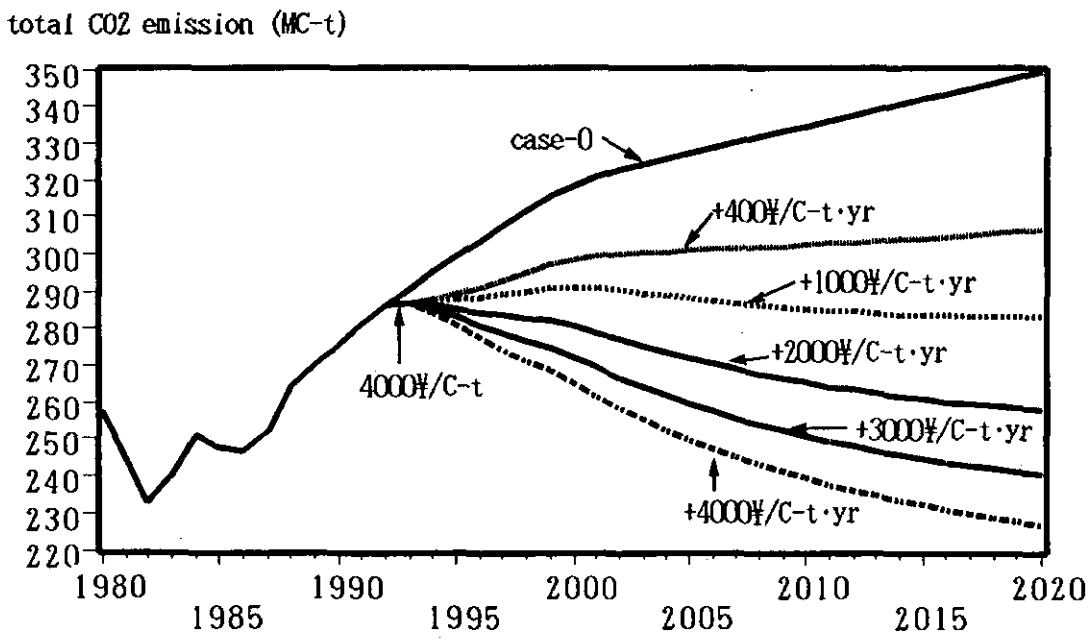

Figure 9 Simulation results: the changes of total CO2 emission (MC-t) in cases of carbon emission taxes with 4000 ¥/C-t initial value and 400, 1000, 2000, 3000, and 4000 ¥/C-t·year escalation

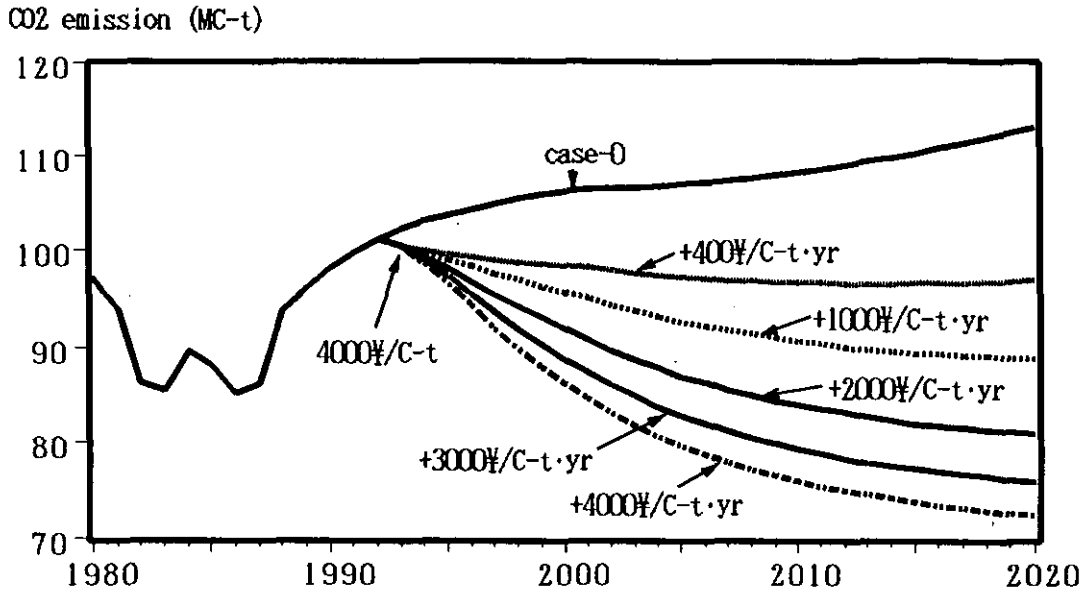

Figure 10 Simulation results: the changes of CO2 emission (MC-t) off industry sector; in cases of carbon emission taxes with 4000¥/C-t initial value and 400, 1000, 2000, 3000 and 4000¥/C-t·year escalations

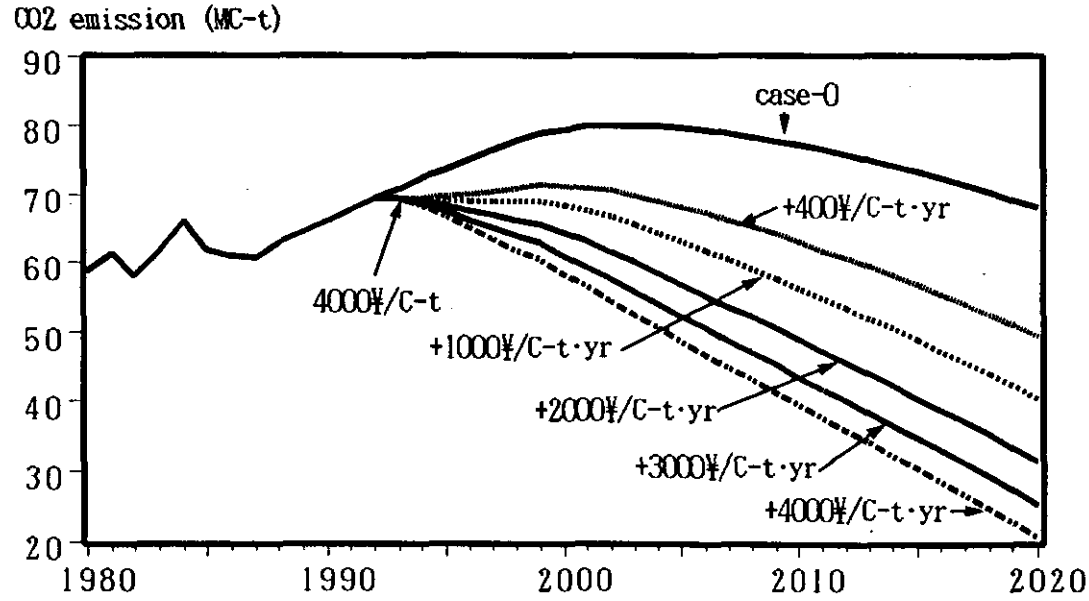

Figure 11 Simulation results: the changes of CO2 emission (MC-t) of electric power generation sector; in cases of carbon emission taxes with 4000¥/C-t initial value and 400, 1000, 2000, 3000 and 4000¥/C-t·year escalations

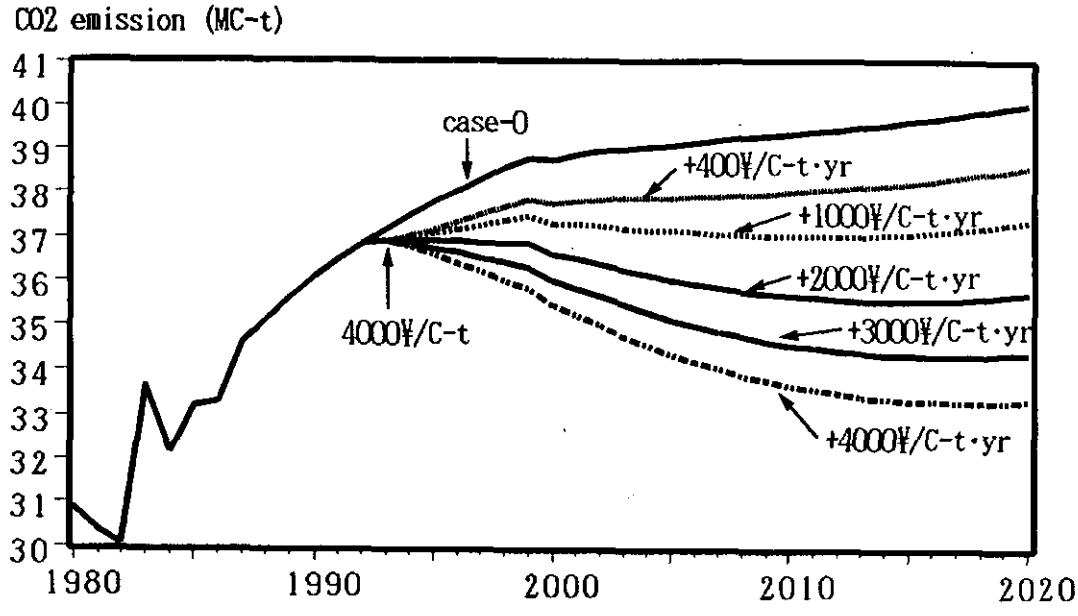

Figure 12 Simulation results: the changes of CO2 emission (MC-t) of services, household and public sector; in cases of carbon emission taxes with 4000¥/C-t initial value and 400, 1000, 2000, 3000 and 4000¥/C-t·year escalations

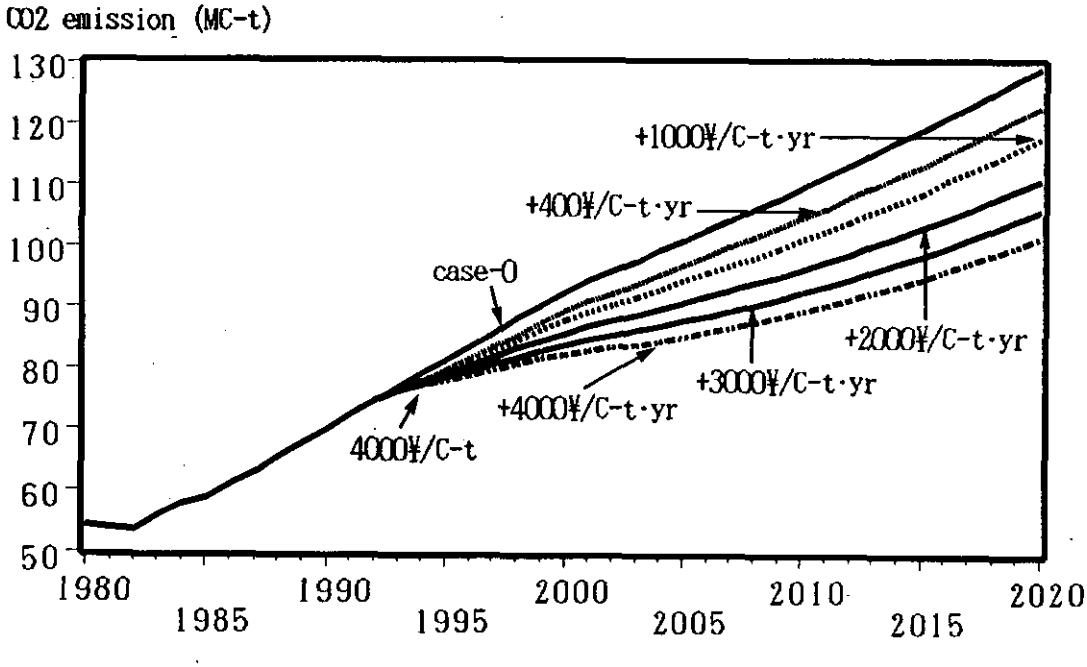

Figure 13 Simulation results: the changes of CO2 emission (MC-t) of transportation sector; in cases of carbon emission taxes with 4000¥/C-t initial value and 400, 1000, 2000, 3000 and 4000¥/C-t·year escalations

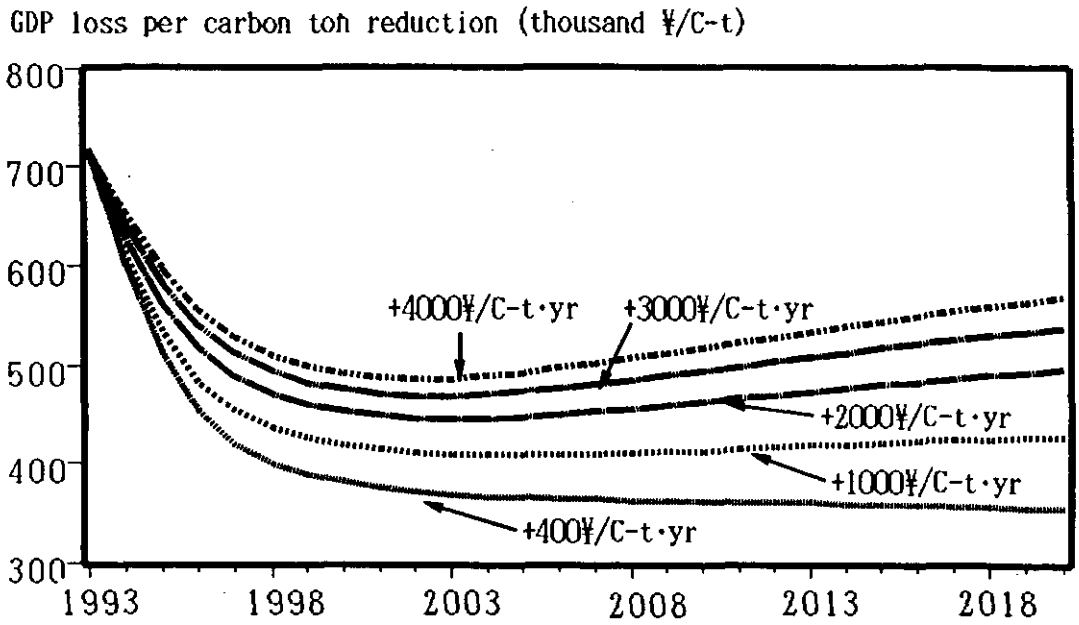

Figure 14 Simulation results: the changes of loss of GDP per carbon ton CO2 emission reduction (thousand ¥/MC-t) in cases of carbon emission taxes with 4000¥/C-t initial value and 400, 1000, 2000, 3000 and 4000¥/C-t·year escalations

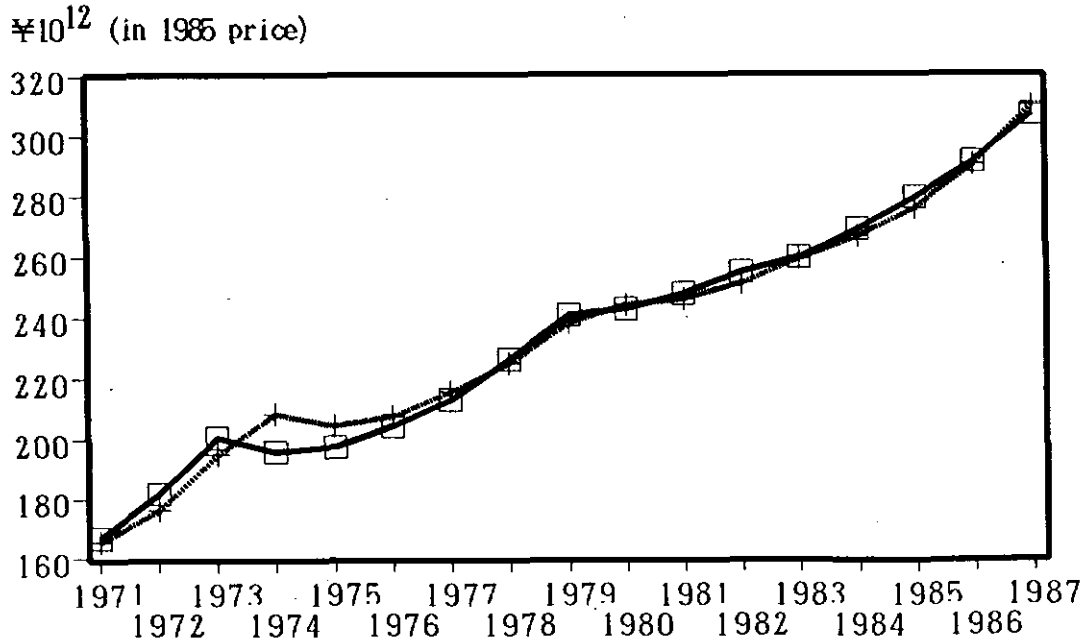

Figure A-1 Historical and theoretical Gross Domestic Demand values (□:historical data ,+ :theoretical values)

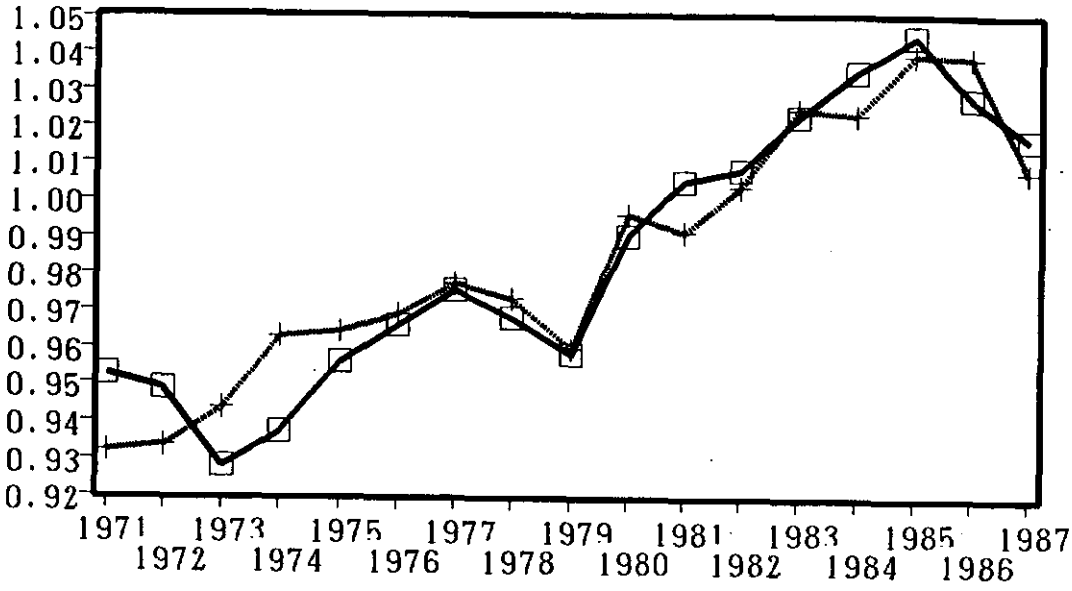

Figure A-2 Historical and theoretical ratios(GDP/Gross Domestic Demand)
(□:historical data ,+ :theoretical values)

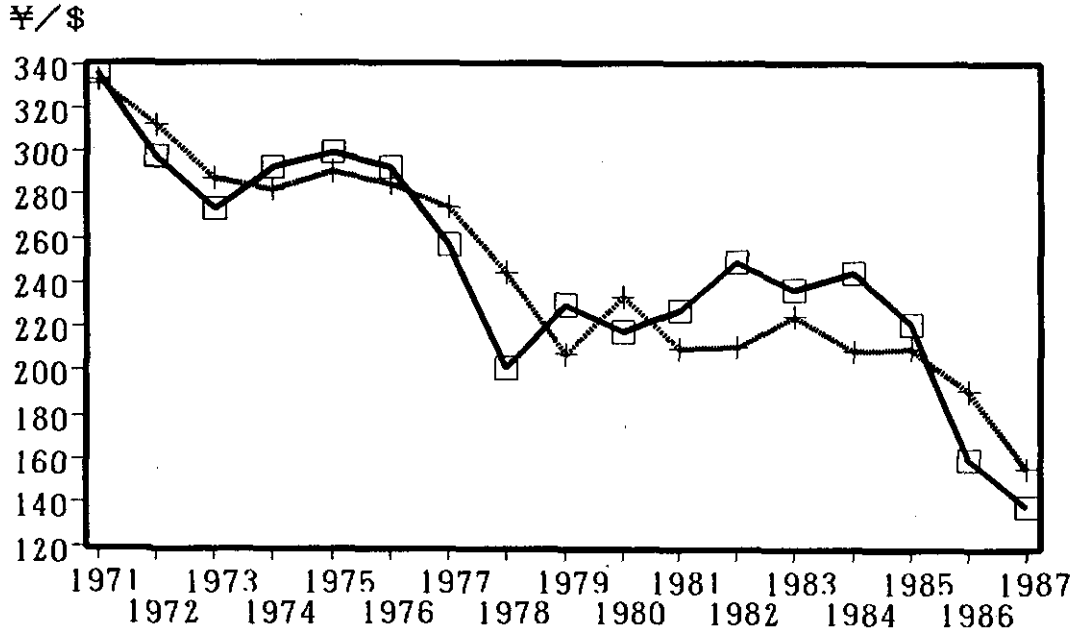

Figure A-3 Historical and theoretical exchange rate values
(□:historical data ,+ :theoretical values)

Table 1 Estimated parameters of the energy demand functions

$$\ln D_t = \alpha \ln D_{t-1} + \beta \ln Y_t + \gamma \ln P_t + C$$

D:demand Y:real GDP P:1985 prices

sector	α	β	γ	C	R^2
thermal use	.738	.116	-.162	4.16	.939
(industry)	(6.80)	(1.20)	(4.74)	(2.36)	6.55
electricity	.490	.392	-.162	4.73	.905
(industry)	(3.44)	(4.05)	(2.83)	(3.08)	1.57
naphtha	.524	-.139	===	6.10	.512
	(2.53)	(1.58)		(2.33)	1.84
coke	-.005*	.633	.083	10.14	.766
	(2.30)	(6.37)	(2.24)	(28.5)	1.26
thermal use	.700	.139	-.034	3.32	.923
(public)	(6.02)	(1.23)	(.750)	(3.47)	2.80
electricity	.773	.296	-.032	1.30	.994
(public)	(7.09)	(1.84)	(.532)	(2.34)	2.14
heavy oil	.255	.052	-.153	8.12	.711
(public)	(1.49)	(.492)	(3.19)	(4.43)	1.83
coal	.381	-1.48	-0.04	12.33	.872
(public)	(1.47)	(2.23)	(.249)	(2.12)	2.04
light oil	.227	1.038	-.154	3.75	.990
(transport.)	(1.99)	(7.43)	(3.80)	(8.13)	2.08
gasoline	.796	.1049	-.045	2.11	.983
	(6.99)	(1.26)	(.710)	(3.76)	2.57
LPG	.294	.0560	.0146	4.74	-.05
	(1.09)	(.317)	(.204)	(2.55)	1.74
electricity	.812	.1326	-.059	1.28	.978
(transport.)	(6.77)	(2.19)	(1.65)	(1.41)	2.86
jet fuel	.922	.113	-.098	1.26	.978
	(9.40)	(.808)	(1.98)	(3.81)	2.59
heavy oil	.815	.1294	-.145	2.41	.752
(transport.)	(6.65)	(.871)	(2.33)	(2.00)	1.59

(1)Values in the parenthesis indicate t-values.

(2)The values in the lower cells of R^2 columns indicate D.W. ratios.

(3) α of coke is the coefficient of year.

(4) β's of coke and naphtha indicate the coefficients of production output indexes of the iron & steel industry and the chemical products industry respectively.

Table 2 Estimated parameters of the Logit share functions models

		coal	kerosine	heavy oil	gas
thermal use of industry sector	A	1.000	.762	1.246	.534
			(2.52)	(3.32)	(2.72)
	α	-.207	-.519	-.736	-.465
		(.672)	(2.36)	(2.99)	(2.59)
	β	.765			
		(8.55)			R^2 = .962
		coal	heavy oil	LNG	
electric power generation	A	1.000	.878	.285	
			(7.75)	(1.317)	
	α	-.238	-.605	-.255	
		(1.60)	(8.93)	(1.847)	
	β	.848			
		(18.2)			R^2 = .974
		kerosine	LNG+LPG		
thermal use of public sector	A	1.000	-.352		
			(2.26)		
	α	-.275	-.140		
		(1.98)	(1.42)		
	β	.437			
		(1.63)			R^2 0.855

(1)Values in the parenthesis indicate t-values.

Table 3 Relations among fossil prices

$\ln P_f = \alpha \ln(P_{heavy\ oil}) + const.$

fuel type	α	const.	R^2	D.W.
(1)coal	.190	7.64	.104	1.24
	(1.06)	(4.20)		
(2)coke	.213	7.30	.230	.482
	(2.46)	(8.08)		
(3)kerosine	.856	1.83	.962	.801
	(20.7)	(4.26)		
(4)light oil	.529	5.72	.934	.446
	(15.5)	(16.1)		
(5)gasoline	.423	7.31	.944	.769
	(17.0)	(28.2)		
(6)naphtha	.982	.088	.861	.290
	(10.3)	(.089)		
(7)LPG	.800	2.30	.749	.684
	(7.20)	(1.99)		
(8)LNG	.954	.557	.940	.852
	(16.4)	(.919		

(1)Values in the parenthesis indicate t-values.

Table 4 Occurrence Probabilities and inter-relations P(i→j)

	A	B	C	D
A	.3	.1	.35	.75
B	.25	.15	.6	.73
C	.5	.12	.5	.75
D	.25	.20	.55	.7

Table 5 Single and second order occurrence probabilities

	A	B	C	D
A	.300	.034	.184	.210
B	.034	.150	.079	.119
C	.184	.079	.500	.379
D	.210	.119	.379	.700

Table 6 Range of scenario probabilities and maximized entropy probabilities

	scenario	min.	max.	entropy max
1)	(0000)	.0572	.1783	.1192
2)	(1000)	.0000	.0906	.0409
3)	(0100)	.0000	.0306	.0153
4)	(1100)	.0000	.0306	.0031
5)	(0010)	.0000	.1210	.0652
6)	(1010)	.0000	.0906	.0431
7)	(0110)	.0000	.0306	.0093
8)	(1110)	.0000	.0306	.0039
9)	(0001)	.1340	.2809	.2034
10)	(1001)	.0000	.1163	.0641
11)	(0101)	.0063	.0709	.0447
12)	(1101)	.0000	.0340	.0087
13)	(0011)	.1164	.2714	.1950
14)	(1011)	.0593	.1840	.1184
15)	(0111)	.0145	.0791	.0474
16)	(1111)	.0000	.0340	.0183

Table 7 Parameters of simulation cases

X-I scenario	(1)-1	(2)-1	(2)-2	(3)	(5)	(9)	(1)-2	(14)
event	CASE-0 refer-ence	CASE-1 supply crisis-1	CASE-2 supply crisis-2	CASE-3 carbon em. tax	CASE-4 regulat. nuclear	CASE-5 cogene-ration	CASE-6 low eco. growth	CASE-7 X-I scenario
GDP potential growth rate θ	1.70% 1.16%	←	←	←	←	←	1.23% .82%	2.5% 1.75%
nuclear & hydro power growth rate	3.45% 3.45%	←	←	←	2.0% 2.0%	3.45% 3.45%	←	2.0% 2.0%
oil supply crisis (price elasticity)	×	○ (0.0)	○ (0.3)	×	×	×	×	○ (0.1)
cogeneration (GW) up. 2000 low. 2020	5GW 15GW	←	←	←	←	8GW 30GW	5GW 15GW	8GW 30GW
carbon emis. tax	×	×	×	○	×	×	×	×
cons. surplus loss ave. per (l·year)[3]	—	72.5(T¥) 96.6¥/l	24.1(T¥) 32.1¥/l	—	—	—	—	41.7(T¥) 55.6¥/l

(1)Price escalation rate oil:3%/year, coal:1%/year and gas 3%/year are assumed for each case.

(2)Values in the upper row are until 2000 and in the lower are after 2000.

(3)Values in the lowest represent the averaged cummulative consumer's surplus loss by year and by liter oil supply reduction.