2.2 A SIMULATION STUDY ON CARBON TAX WITH "FORECAST 21"

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1. INTRODUCTION

Global warming caused by greenhouse effect proves to be a serious threat to sustainable development of mankind. Since the carbon dioxide produced by burning fossil fuels is a dominant source of anthropogenic greenhouse gas emissions, world energy systems should change significantly to cope with global warming problem. Fossil fuels now supply almost 90 percent of world energy requirements, and continue to be principal energy sources at least for the coming several decades. Control of CO2 emission means a strong constraint on energy systems; thus, it might cause significant negative impacts on economic activities and quality of life.

For identifying phased and flexible response strategies, which are required to manage the uncertainties of underlying sciences on the global warming, it is important to evaluate macro-economic costs of measures to control CO2 emissions. The paper presents a simulation study on the cost and effectiveness of carbon tax in Japan.

2. CO2/ENERGY/GNP STATISTICS AND PROJECTIONS

2.1 CO2/Energy/GNP Statistics

As stated in the often cited Kaya paper (Kaya *et al* (1989)), carbon dioxide emission is expressed as a product of three factors:

$$CO2 = (CO2/Energy) \times (Energy/GNP) \times GNP \qquad (1)$$

Let X be CO2/Energy and Y be Energy/GNP. X is an indicator of the carbon intensity of energy supply and Y is an indicator of energy intensity of economy or a reverse indicator of energy efficiency. The lower these two indicators, the less CO2 emission per unit of economic activity. The following relation between the changing rates of these three factors is derived from equation (1):

$$d(CO2)/CO2 = dX/X + dY/Y + d(GNP)/GNP \qquad (2)$$

Namely the growth rate of CO2 emission is expressed as a sum of the rates of changes of these three factors; X, Y, and GNP.

Figure 1 shows the indicators of X and Y calculated from the statistics in 1973 and 1986 for several selected countries. Figure 2 shows the average rates of changes of the two indicators. As shown in these figures, Japan improved the energy efficiency most rapidly (nearly 3%/yr) through the two oil crises along with significant reduction of carbon intensity (almost 1%/yr); thus Japan achieved about 4%/yr GNP growth without increasing CO2 emission between 1973 and 1986. These figures also suggest that both the energy efficiencies and carbon intensities range widely depending on individual country's technological, social, and natural conditions. Planned economy's energy efficiency is generally low and the energy intensities in developing countries increased, to the contrary of those in developed countries, even in the oil crisis era.

Figure 3 shows the CO2/energy/GNP growth rate indicators in Japan for the period from 1970 to 1988 by dividing it into three subperiods; 1970-73, 1973-86, and 1986-88. As

stated in the international comparison, CO2 emissions in Japan were kept constant during the sub-period of high oil prices (1973-86); however, CO2 emissions had increased more rapidly than economic growth rate before the first oil crisis and have been again increasing almost in parallel with GNP since 1986. Thus, it would be too optimistic to extrapolate the performance shown in the period of oil crises to the future.

2.2 CO2 Emission Projections in Japan

Figure 4 shows the base case projection of CO2 emissions made by the Central Research Institute of Electric Power Industry (CRIEPI) of Japan (Nagata *et al* (1991), Yamaji *et al* (1990)). In this projection, CO2 emission in 2005 increases by about 36% from the level of 1988. Average annual growth rates of X(CO2/Energy), Y(Energy/GNP), and GNP for 1988-2005 are -0.4%, -1.4%, and 3.7% respectively; thus, CO2 emission increases at the average rate of 1.8%/year for the same period.

On the other hand, the Ministry of International Trade and Industry (MITI) of Japan released the latest official Long-term Energy Outlook in June, 1990. In the MITI's outlook, which covers the period up to the year 2010, CO2 emissions are estimated to increase by 16% in 2000 and by 18% in 2010 from the level of 1988. Average annual growth rates of X, Y, GNP, and CO2 for 1988-2010 are -0.7%, -2.0%, 3.6%, and 0.8% respectively.

In the MITI's energy outlook, it is considered that utmost efforts to reduce CO2 emissions such as rapid improvement of energy efficiency (2%/yr reduction rate of energy intensity of GNP) and maximum possible nuclear power development (72.5 GWe in 2010) have been already incorporated. We adopt the CRIEPI's projection as a base case in the following simulation study.

3. FRAMEWORK FOR CARBON TAX SIMULATION

3.1 FORECAST 21

CRIEPI's medium-term economic forecasting system "FORECAST 21" (Ymaji (1989)) was adopted as a simulation tool for carbon tax policy analysis. The system consists of four models: World Energy Model, Medium-term Multi-sectoral Model, Inter-fuel Competition Model, and Nine-Region Model. The system was also used to make CRIEPI's base case CO2/energy/GNP projections described in the previous section. World Energy Model and Nine Region Model were not used in the assessment of CO2 reduction policies because import energy prices are given exogenously and Japan is treated as an aggregate region in the policy analysis.

3.2 Cases of Carbon Tax Analysis

According to the CRIEPI's base case projection, the level of CO2 emission in 2005 will be 36%, around 100 million ton of carbon, higher than that in 1988. Starting from this base case projection, let us assume to introduce carbon tax to hold the CO2 emission in 2005 as it is in 1988. The carbon tax is to be introduced in 1990, and the level of the tax is increased gradually to maintain the effect of the tax.

We assume that the carbon tax is imposed on primary energy sources in proportion to theoretically estimated CO2 emissions. Both direct impact of the tax through raised fossil fuel prices and indirect impact through changes in economic outputs and general prices are evaluated by the CRIEPI's FORECAST 21. Depending on the ways to use the revenue of the carbon tax, we set two cases: Case 1 "Tax Remove Case" and Case 2 "Tax Offset Case". In Case 1 collected tax revenues are assumed to be removed from the Japanese economy; and, in the Case 2 the revenue of the tax is offset by the equivalent amount of income tax reduction.

4. CARBON TAX FOR CO2 STABILIZATION IN JAPAN[2,3]

Through several simulation experiments we found the tax schedule to hold the CO2 emission in 2005 approximately at the level of 1988. As stated in Figure 5, the tax schedule to achieve the target is as follows: tax with a rate of 4,000 yen per ton of carbon is introduced in 1990 , and then the tax rate is increased yearly by 4,000 yen until it reaches 64,000 yen per ton in 2005. As also shown in Figure 5, the carbon tax raises oil price in 2005 to the level of about 2.8 times as much as that in the base case projection. Reductions of CO2 emissions caused by the tax are illustrated in Figure 6.

5. MACRO-ECONOMIC IMPACTS OF CARBON TAX POLICY[2,3]

The macro-economic impacts of the carbon tax policy to hold the CO2 emission constant are summarized in Table 1 and illustrated in Figure 7. The results lead to the following findings:

CO2 emission stabilization through price effects of the carbon tax has a serious impact on national economy in Japan: in the Tax Remove case, average growth rate of GNP in real term from 1988 to 2005 reduces by 0.4%/year and GNP in 2005 decreases by 38 trillion yen(1980), more than 6% from the base case value.

Income tax reduction offsetting the carbon tax revenue mitigates the adverse macro-economic impacts: loss of GNP in 2005 in the Tax Offset case is reduced to 30 trillion yen(1980), about 5% of the base case value; however, the effect is too small to make carbon tax an attractive policy to Japan.

GNP losses per unit CO2 emission reduction range from 250 thousand yen/ton-C (cumulative average in the Tax Offset case) to 360 thousand yen/ton-C (2005 year only in Tax Remove case). The specific CO2 reduction costs associated with carbon tax in Japan are prohibitively high when compared with the cost estimates of various technical measures to reduce CO2 emissions, mostly less than 50 thousand yen/ton-C.

6. CONCLUDING REMARK

There remain many issues which were not analyzed in the study. Among them, we identify the following points:

To evaluate the effect of using the tax revenue as a fund for subsidy to accelerate market penetration of specific technical measures for reducing CO2 emission.

To investigate the influence on global CO2 emission through international economic impacts which would be caused by structural changes of Japanese economy to reduce Japan's CO2 emission.

To clarify what happens if many countries introduce CO2 tax simultaneously.

To identify the possible advantages which could be achieved through regional and/or global interactions to reduce the global CO2 emissions more efficiently, e.g. technology transfer and international trade of CO2 emission permits.

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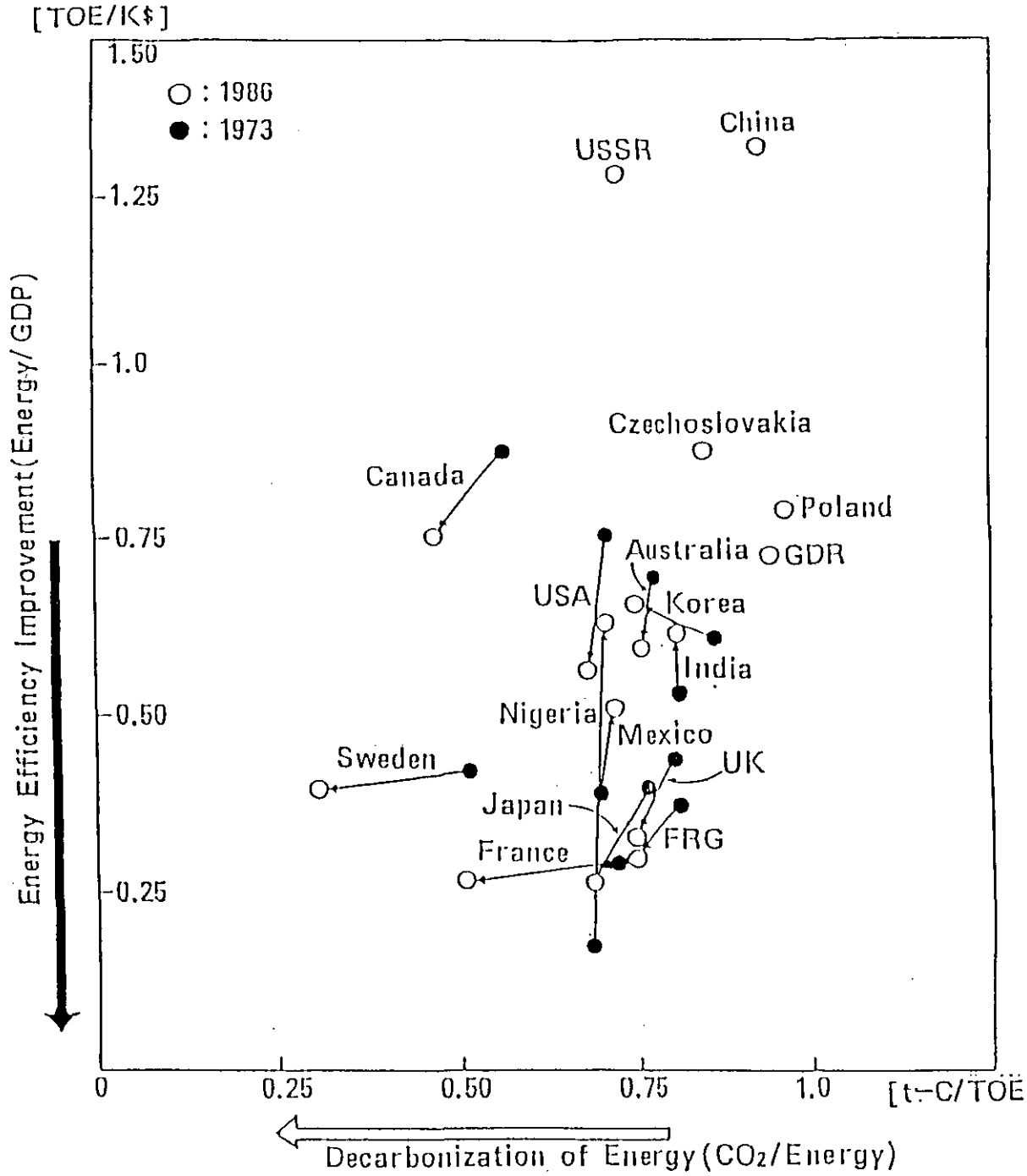

Figure 1 CO2 Reduction Efforts during 1973-1986

Source: *OECD Energy Balances*, IEA/OECD.
World Energy Statistics and Balances, IEA/OECD, 1989.
International Financial Statistics, IMF.
CO2 Emission Unit: Coal 0.996, Oil 0.807, Gas 0.574(t-C/TOE).

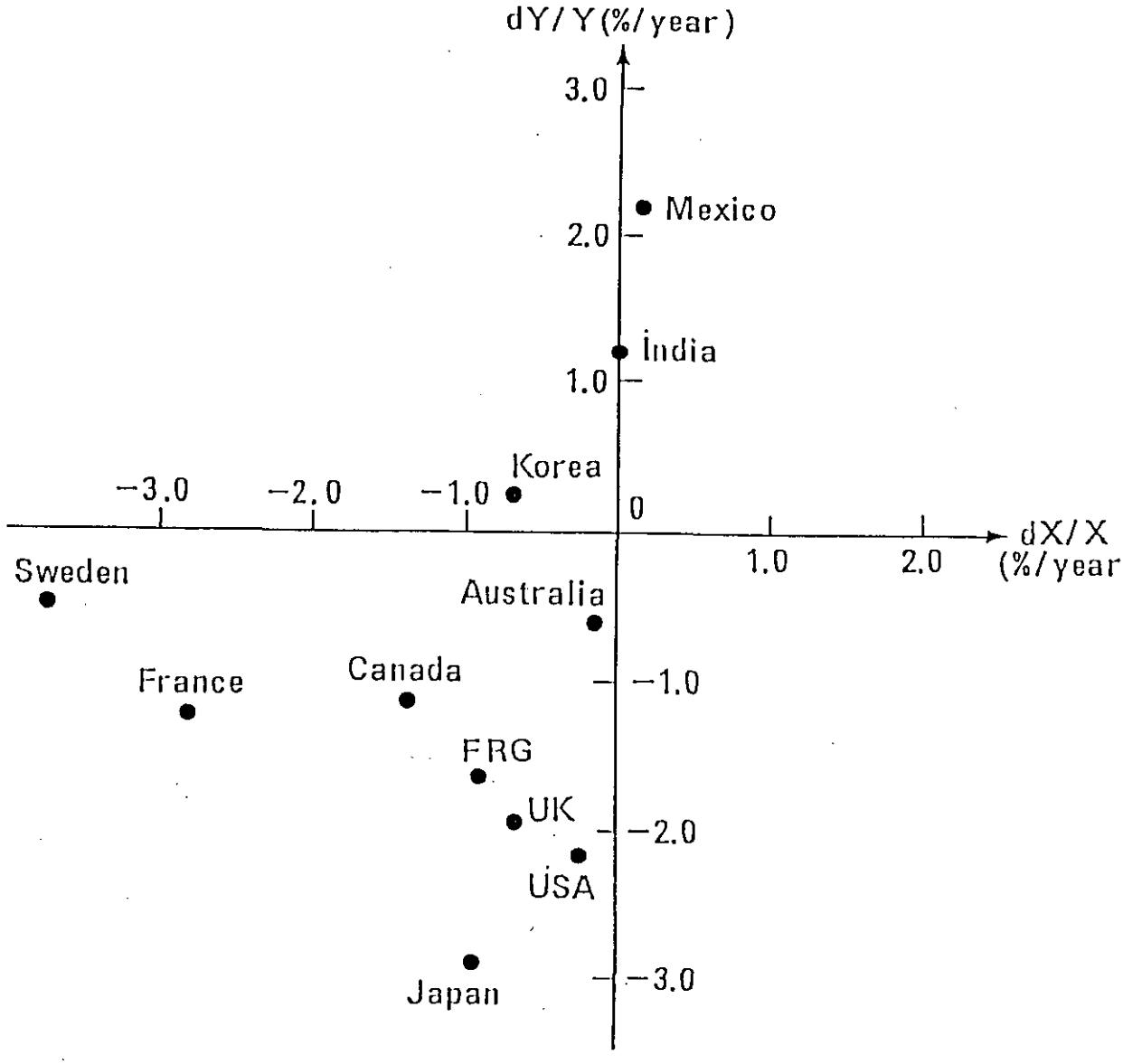

Figure 2 Comparative Efforts for CO2 Emission Reduction during 1973-1986

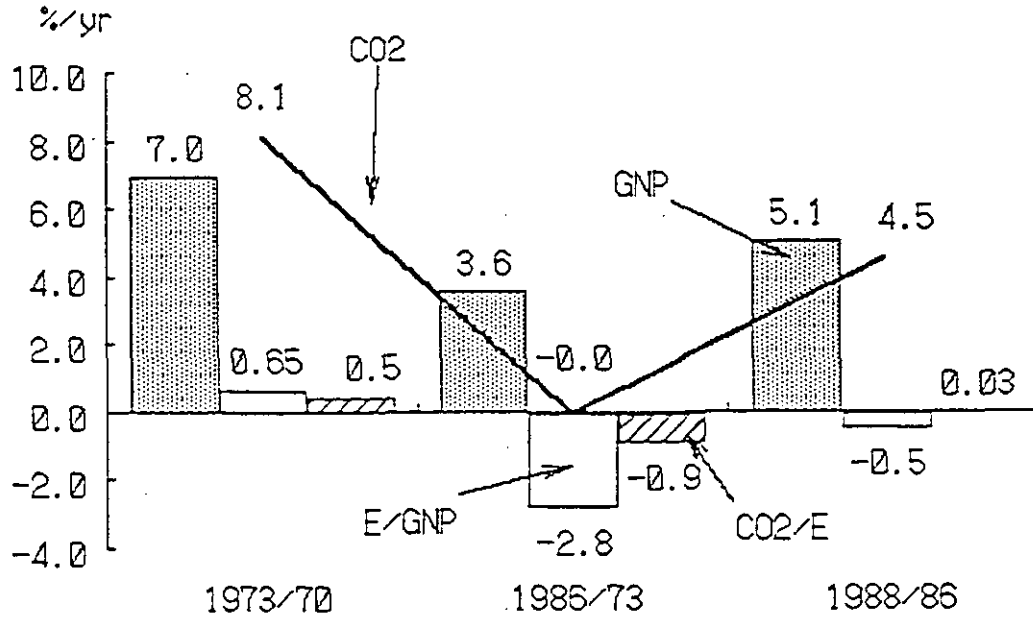

Figure 3 CO2/Energy/GNP Growth Rate Indicators during 1970-1988

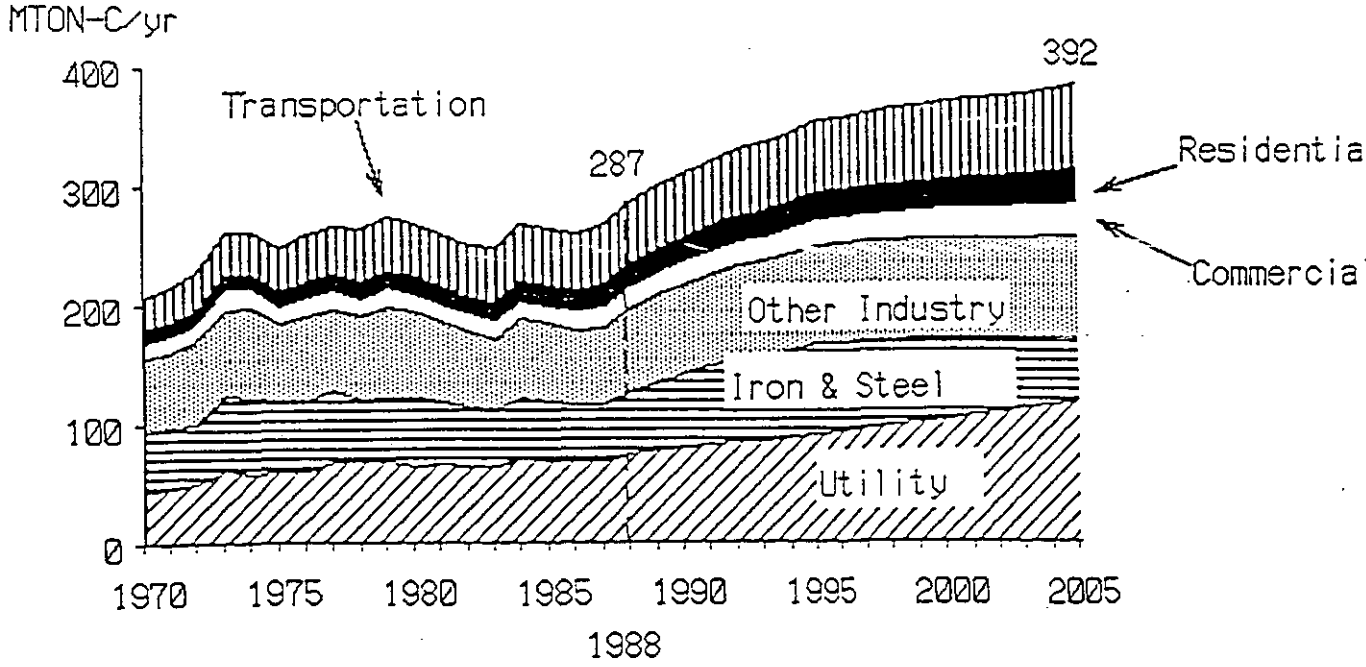

Figure 4 CO2 Emission in Japan

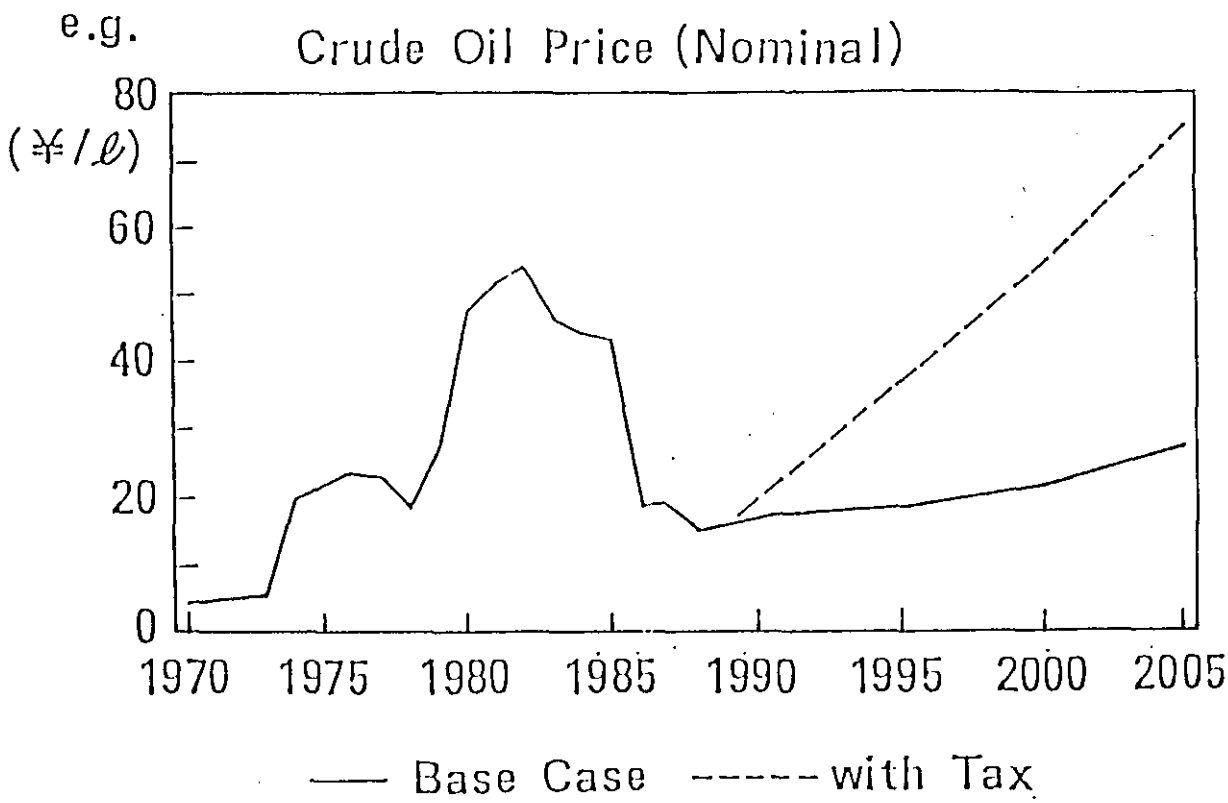

Figure 5 Carbon Tax for Holding CO2 Emission Constant
- Introduce in 1990 with a level of : ¥4,000/t-C
- Then, the tax level increases yearly by ¥4,000 afterwards, i.e. ¥64,000/t-C in 2005

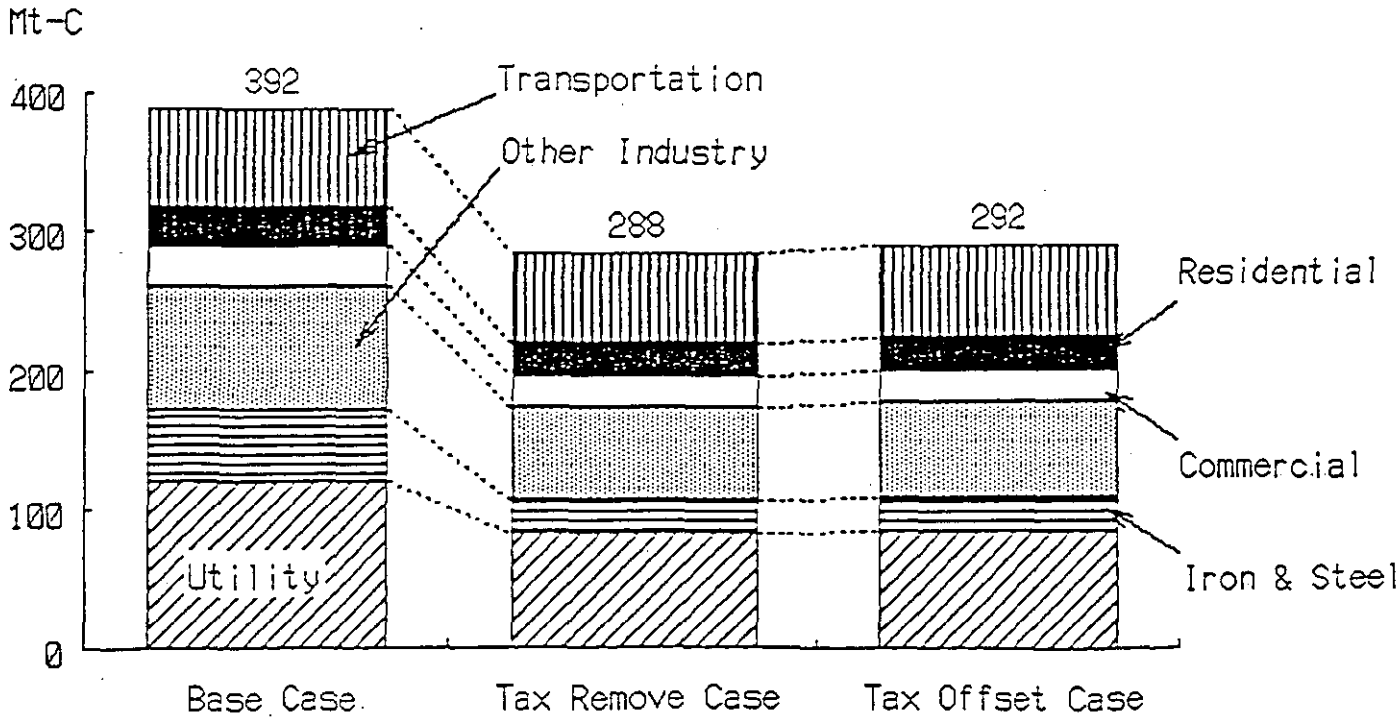

Figure 6 CO2 Emission in 2005

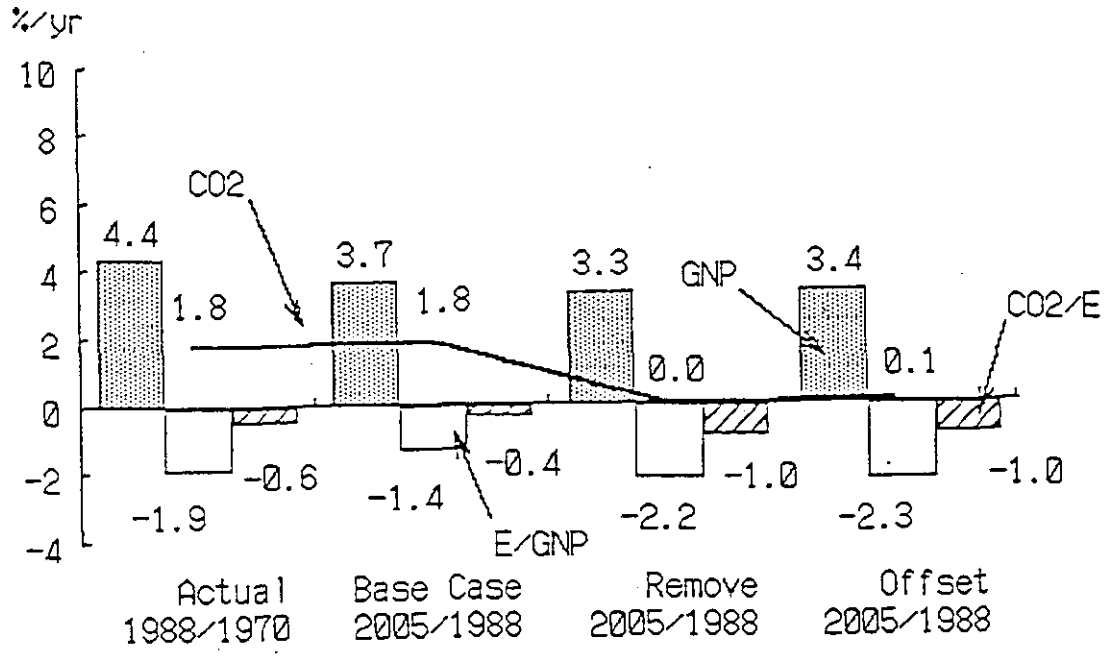

Figure 7 CO2/Energy/GNP Growth Rate Indicators during 1970-2005

Table 1 Costs and Effects of Tax for CO2 Reduction

	Tax Remove Case	Tax Offset Case
A. Real GNP Loss (Trillion ¥)		
in 2005	-37.7 (-6.2%) *2	-30.0 (-4.9%)
1990～2005, Cumulative	-310.6 (-4.0%)	-230.6 (-3.0%)
	(-0.4%, Annualy)	(-0.3%, Annualy)
B. CO_2 Reduction (Mil. C-ton)		
in 2005	104.1 (26.6%)	99.8 (25.5%)
1990～2005, Cumulative	985.1 (17.1%)	939.0 (16.3%)
C. Tax Revenue (Trillion ¥) *1		
in 2005	11.9	12.0
1990～2005, Cumulative	118.2	119.0
D. Specific CO_2 Tax Revenue (Thousand ¥ / C-ton)		
1990～2005, Nominal	31.4	31.5
1990～2005, Real Price *1	23.4	23.3
E. National Economic Cost per CO_2 Reduction (Thousand ¥ / C-ton)		
in 2005	362	301
1990～2005, Cumulative	315	246

*1 Deflated by wholesale price index (Real Price in 1980)
*2 Difference rate from Base Case