2. Medium- and Long-term Models

2.1 MACRO-ECONOMIC COSTS OF CO2 EMISSIONS CONTROL POLICIES IN JAPAN

Noriyuki Goto

Faculty of Economics
Kanazawa University

1. OBJECTIVE

This study is aimed at analyzing the expected costs of various carbon dioxide (CO2) emissions control policies. The policies examined include the introduction of a carbon dioxide tax, direct control of the annual rate of CO2 emissions and direct (or planned) control of its maximum possible accumulation in the atmosphere. Numerical computations are undertaken to determine the shadow price of one-unit reduction of CO2 emissions. This shadow price may be interpreted as an imputed price for a tradable emissions permit for one unit of CO2. Also, macro-economic costs incurred by the CO2 controls are estimated.

The analytical model, which is called the "GDMEEM" (Goto Dynamic Macro-Energy Equilibrium Model), simulates a future dynamic equilibrium path that is optimal under the assumption that the markets for both primary and secondary energy sources are efficient. The model is an integration of two underlying models: a linear programming model that reflects information on existing energy conversion technologies, as well as future prices of primary energy resources; and a simple macro-econometric model that relates energy demand to macro-economic activities. The integrated model is solved so that a specified measure of social welfare is maximized. The basic structure of the GDMEEM is illustrated in Appendix.

The model's optimal solution may be interpreted as follows: Assume that consumers and firms behave rationally given the exogenously projected amounts of factor inputs (labor and capital), the long-run supply curves of primary energy resources, and the alternate energy conversion technologies. Consumers determine their demand for energy so that their utility is maximized, subject to their income constraint. Firms in non-energy industries determine their demand for energy so that they maximize their value added. The competitive energy sectors meet the total demand they face, in such a way that their production cost is minimized, given existing conversion technologies and the available amount of energy resources. Then the market equilibrium solution, where total energy demand equals total energy supply and the macro-economic social welfare function is maximized, may be derived.

The CO2 emissions may be directly estimated if the quantity of each fossil fuel consumed is known. If a carbon dioxide tax is employed, an increase in the price of fossil fuels results. An introduction of either of the two forms of direct CO2 emissions controls (upper-limits on either annual emissions rate or total accumulation) is analyzed by imposing the appropriate upper-limit constraint on the quantity of CO2 emissions

In this paper we attempt to provide quantitative answers to the following questions: (1) how much must be paid to fulfill a given emissions control target? (2) how effective is a CO2 tax and what is its impact on macro-economic growth ?

2. METHODOLOGY FOR SIMULATING AN EQUILIBRIUM SOLUTION

This section briefly interprets the model and its optimal solution. Figure 2.1 shows how a certain profit maximizing industrial sector with production function F(Q), efficiently responds to CO2 emissions control. The production function F(Q) relates the maximum possible value added by labor, capital and energy to the amount of energy input Q. We will not explain how the residential sector behaves, but, by replacing the industrial sector's production function with the residential sector's utility function and assuming utility-maximizing behavior, we can interpret the story in a similar manner.

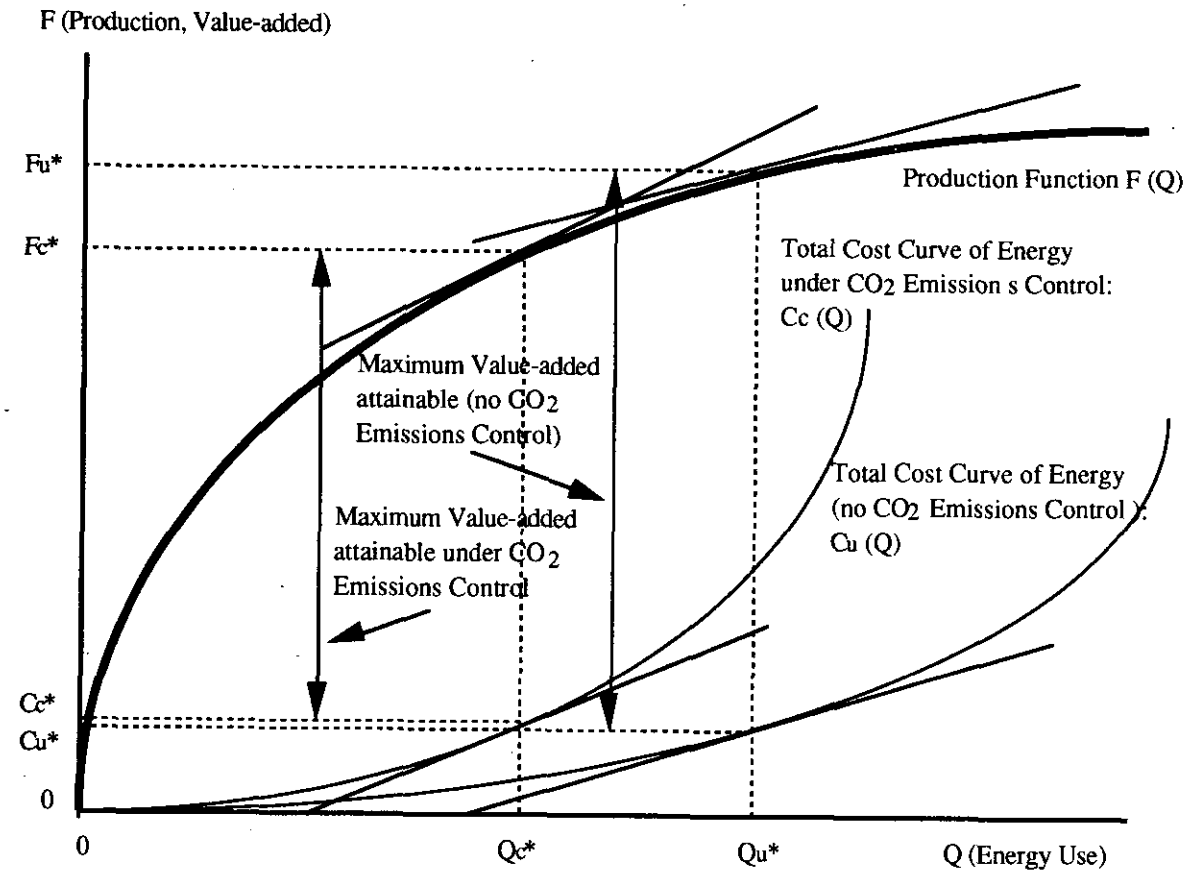


Figure 2.1 Economic Adjustment to CO_2 Emission Controls

In case of no CO2 emissions control, the total cost function, Cu(Q), is determined only by the scarcity of available resources. The profit-maximizing firm demands energy, say Qu*, such that marginal benefits equal marginal cost, i.e., dF(Qu*)/dQ = dCu(Qu*)/dQ. Then the output is Fu*=F(Qu*), and the value added by labor and capital is given by Fu* - Cu*.

Next, consider the case in which certain CO2 emissions controls are employed. In the case of direct controls, firms will inevitably switch to energy sources with lower CO2 emissions but higher prices. In the case of indirect controls, typically carbon dioxide taxation, prices of fossil fuels increase by an amount proportional to the tax rate and their carbon contents. In either case, the total cost function for energy shifts up, for example, from Cu(Q) to Cc(Q). The energy demanded by the profit-maximizing firm decreases to Qc*, the solution to the optimality condition: dF(Qc*)/dQ= dCc(Qc*)/dQ. Consequently, the output and value added decrease to Fc* and Fc* - Cc*, respectively.

Therefore, the macro-economic costs incurred from imposing CO2 emissions controls (subsequent to efficient economic adjustments by firms), might be evaluated by the decrease in value added; an aggregation for the whole industries, namely the gross domestic product: i.e., Σ[(Fu* - Cu*) - (Fc* - Cc*)]. In case of CO2 taxation, we assume the

neutrality of tax. That is, the macro-economic cost is evaluated by $\Sigma[(Fu^* - Cu^*) - (Fc^* - Cc^*) - Tax]$, since the total energy cost Cc^* includes the tax payments.

Note that, in order to focus upon the energy market, we simply assume that the non-energy factor input, N(t), is exogenously given. This is approximately equivalent to the neoclassical assumptions of full-employment in the labor market and the optimal accumulation of capital. The non-energy factor prices may be determined so that the equilibrium conditions are satisfied.

3. RESULTS OF SIMULATIONS

Table 3.1 gives the results of the simulation for the business as usual (BAU) case.

Table 3.1 Simulation Results for the Business as Usual (BAU) Case

Calendar Year	1990	2000	2010	2020	2030	2040
GNP (¥ 10^9/yr)	416,421	585,945	805,424	1,078,808	1,431,672	1,820,492
Avg. Growth Rate (%/yr)		(3.42)	(3.18)	(2.92)	(2.83)	(2.40)
Energy Demand (10^{12} kcal/yr)	3127	3887	4610	5433	6491	7424
Avg. Growth Rate (%/yr)		(2.18)	(1.71)	(1.64)	(1.78)	(1.34)
Avg. Energy Price (¥ $10^3/10^6$kcal)	5.7	7.7	10.1	12.6	14.8	16.6
Avg. Growth Rate (%/yr)		(3.01)	(2.71)	(2.21)	(1.61)	(1.15)
Share of Electricity (%)	20.1	21.7	23.2	25.6	27.1	31.4
Share of Non-electric Energies (%)	79.9	78.3	76.8	74.4	72.9	68.6
CO_2 Emission (10^9 ton-C/yr)	0.318	0.418	0.487	0.568	0.648	0.715
Avg. Growth Rate (%/yr)		(2.73)	(1.53)	(1.54)	(1.32)	(0.98)
CO_2 Buildup (10^9 ton-C)	0.796	2.727	4.907	7.382	10.096	11.647

Note: "Avg. Growth Rate" figures denote averages during the 10 years preceding the year specified.

The BAU case is employed as a reference case, or a yardstick to compare with cases in which some CO2 emissions controls are in force. Summarizing briefly, for the BAU case, the annual growth rate of GNP declines gradually from 3.4% in the period 1990-2000 to 2.4% in 2030-2040. The average annual growth rate of GNP from 1990 to 2040 is 2.95%. Although total energy demand increases with GNP, the annual rate of increase slows down from 2.2% during 1990-2000 to 1.3% in the last decade due to rising energy prices and the subsequent structural changes in the economy. The average annual rate of increase in total energy demand during the entire period is 1.7%, while that in average energy prices is 2.1%. The share of electricity in total energy demand rises gradually from 20% in the year 1990 to more than 30% in 2040. This is due to the relatively low price elasticity of the demand for electricity. The annual rate of CO2 emissions is estimated to be 320 million tons in the year 1990, where and in what follows the amount of CO2 is measured in terms of its carbon content. Without any emissions control the volume will be doubled around the year 2030, and reach 715 million tons in the year 2040. At the end of the period the total accumulated stock of CO2 is estimated to be 11.6 billion tons.

Table 3.2 lists eighteen CO2 emissions control cases: seven involve direct control of the annual rate of CO2 emissions; five involve direct control of the accumulation of CO2; and six involve indirect control by taxation.

Table 3.2 Parameter Values in Each CO2 Emission Control Case

Case	CO_2 Emission Control		
	Direct Control		Indirect Control
	Upper-limit of Emission	Upper-limit of Buildup	Tax Rate
	10^9 ton-C/yr	10^9 ton-C	¥10^3/ton-C (1990 Prices)
BASE CASE	-	-	-
EMS - 0.30	0.30	-	-
EMS - 0.31	0.31	-	-
EMS - 0.32	0.32	-	-
EMS - 0.34	0.34	-	-
EMS - 0.36	0.36	-	-
EMS - 0.38	0.38	-	-
EMS - 0.40	0.40	-	-
BLD - 6.00	-	6.00	-
BLD - 6.50	-	6.50	-
BLD - 7.00	-	7.00	-
BLD - 8.00	-	8.00	-
BLD - 9.00	-	9.00	-
TAX10PV	-	-	10.00
TAX15PV	-	-	15.00
TAX20PV	-	-	20.00
TAX30PV	-	-	30.00
TAX40PV	-	-	40.00
TAX50PV	-	-	50.00

Notes: (1) The restrictions apply at all times from 1990 through 2040.
(2) " - " means no restrictions.

Limit the annual rate of CO2 emissions at the 1990 level (EMS-0.32)

Among the various control policies considered, we briefly summarize the results for the EMS-0.32 case in which the annual rate of CO2 emissions is frozen at the 1990 level (i.e., 320 million tons). The total loss of GNP during the planning period is 55 trillion yen (the value is converted to the present value) , which is 0.44% of the total GNP in the BAU case. This implies that one can freeze CO2 emissions at 1990's level only by bearing 55 trillion yen in the coming 50 years (i.e., 1.1 trillion yen per year, on average). The loss of GNP, measured in current value, is 1.3 trillion yen (0.22%) in the year 2000, 6.1 trillion yen (0.76%) in 2010 and 14.2 trillion yen (0.99%) in 2040. It should be emphasized that these losses are estimated assuming perfectly efficient adjustments are made by economic agents with perfect foresight. In reality, larger losses might be experienced depending upon the degree of adjustment inefficiencies.

If CO2 emissions are frozen at the 1990 level then, compared to the BAU case, total energy demand decreases by 17% in the year 2000, 25% in 2010, and 32% in 2030. The corresponding rises in average energy prices are 60%, 107% and 135%, respectively. The average rate of increase in energy demand declines from 1.71% in the BAU case to 1.06% during the period from 2000 to 2030. CO2 emissions are reduced, for example, by substituting from coal to LNG. By freezing CO2 emissions at the 1990's level, the accumulation of CO2 in the terminal year 2040 is reduced from 11.6 billion tons to 7.1 billion tons (i.e., 39% reduction is attained).

In the EMS-0.32 case, the shadow price of CO2 emissions associated with the control is ¥24,660/ton-C on average: ¥26,710/ton-C in the year 2000, ¥32,500/ton-C in 2010, and ¥18,000/ton-C in 2030, all evaluated in 1990 prices. The decline of the shadow price from the year 2010 to the year 2030 is mainly due to the expansion of nuclear power

generation. As mentioned earlier, the shadow price is the marginal cost of one ton-C reduction of CO2 emissions from the control level and hence, the higher the shadow price is, the more costly it is to implement further reduction in CO2 emissions.

Let us briefly review the cases with different levels of emissions controls for sensitivity analysis. If the upper-limit on annual CO2 emissions is decreased to 300 million tons (the EMS-030 case), the necessary adjustment cost (total GNP loss, the present value) is increased to 79 trillion yen, which is 49% higher than the EMS-032 case in which emissions were frozen at the 1990 level. Also, the shadow price rises by 37% to ¥33,840/ton-C. The accumulation of CO2 in the terminal year 2040, is reduced by 3% to 6.9 billion tons. Alternatively, if the upper-limit on the annual rate of CO2 emissions is relaxed by 20 million tons (the EMS-0.34 case), then the necessary adjustment cost decreases by 35% to ¥35 trillion; the shadow price is pushed down by 18% to ¥20,190/ton-C; and the accumulation of CO2 is increased by 6% to 7.6 billion tons.

Case studies

In what follows, based on the computational results obtained, we discuss our major findings in terms of several key economic and CO2-related indices which we are most interested in.

Figure 3.1 exhibits the relationship between the controlled level of annual CO2 emissions rate and the macro-economic cost that is measured by the average loss of discounted GNP during the period 1990 - 2040. The figure clearly shows that the marginal cost, or the incremental cost of reducing CO2 emissions increases as the reduction level is raised.

Figure 3.2 shows the relationship between the average macro-economic cost and the total accumulation of CO2 in the year 2040. Results for both direct and indirect tax controls are plotted in Figure 3.2. Several interesting observations are obtained from this figure.

First, the effect of both direct and indirect controls is quite strong, even when a control policy is only moderately introduced. The result completely agrees with Nordhaus(1990) who finds that the first unit of reduction of CO2 is virtually free. Thereafter, the marginal benefit decreases gradually. Which specific point on the curve to choose is difficult to determine and should be decided by maximizing a social welfare function. However, Figure 3.2 strongly suggests that taking initial steps to control CO2 emissions is very important and effective, even if they are quite mild.

Second, direct control of the annual rate of CO2 emissions is a less effective policy instrument than the direct control of CO2 accumulation or the indirect control of CO2 emissions by taxation. For example, to achieve the same level of reduction in terms of accumulation, policies which directly control annual CO2 emissions cost much more than the other two control policies. The inefficiency of rate control policies is due to their myopic characteristic; dynamic adjustment based on a long-term planning is more effective.

Third, a surprising result is that the CO2 accumulation control policy and the indirect control policy by taxation are almost equally efficient. Therefore, our study lends some support to international public opinion which recommends CO2 taxation as a most efficient control policy.

Figure 3.3 shows the relationship between CO2 accumulation and both the shadow price of and the tax rate on one ton-C of CO2 emissions. We find there that the marginal effectiveness of the control policy decreases as the restriction gets stronger, which may be quite useful for the evaluation of various control policies and the determination of the target control level.

Figure 3.4 illustrates the relationship between the size of the tax imposed and the average macro-economic cost. The results would imply that , if the economy adjusts

efficiently, the macro-economic costs incurred by reducing CO2 emissions are not very large as are normally anticipated.

Figure 3.5 compares our results on the relation between CO2 emissions tax and the percentage reduction in CO2 emissions with similar studies in other countries or regions, in which figures except for our study are recalculated, by Nordhaus(1990), from the original estimates to indicate nearly equivalent measures. It seems to support a widely recognized view that energy utilization in Japan is already more efficient than those in the other countries, hence that further adjustments to CO2 reduction would be more costly. However, considering that our study assumes neither future technological improvements in energy uses nor a clean backstop technology (the large differences for higher taxes are clearly caused by this) and that there exist other various differences in the structure and implicit assumptions among the models, it would be more appropriate to interpret the results as an indication that we can discuss the CO2 issue basically on the same ground and acheive an agreement for a desired global policy coordination.

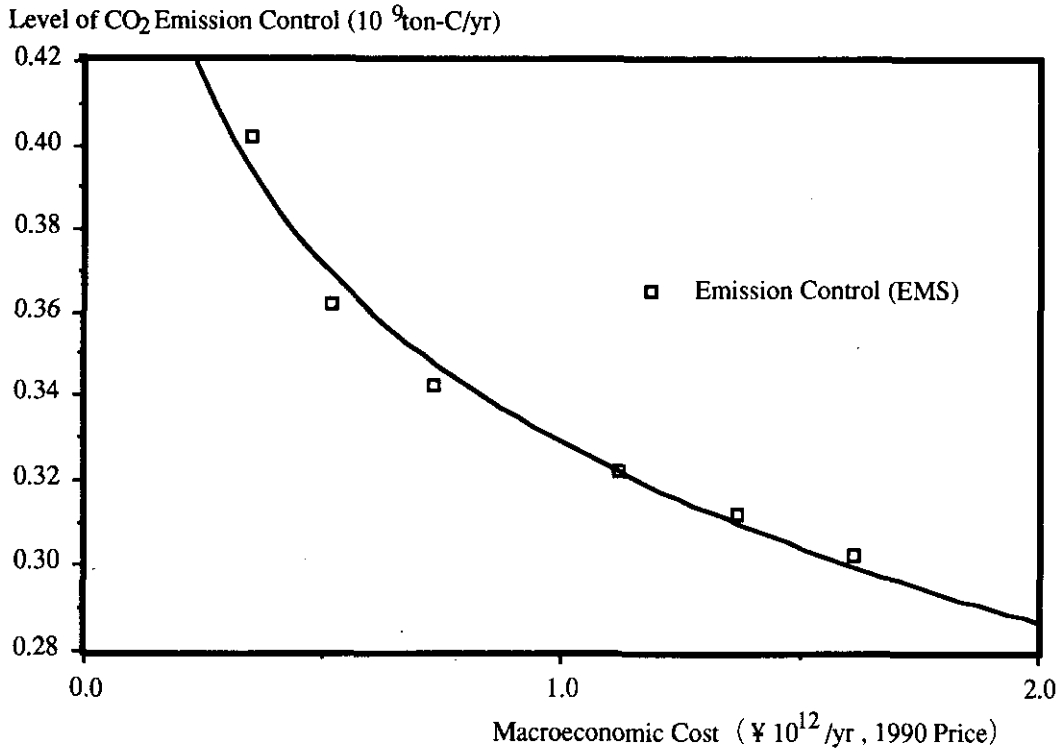


Figure 3.1 CO2 Emissions Control Levels vs. Macro-economic Cost

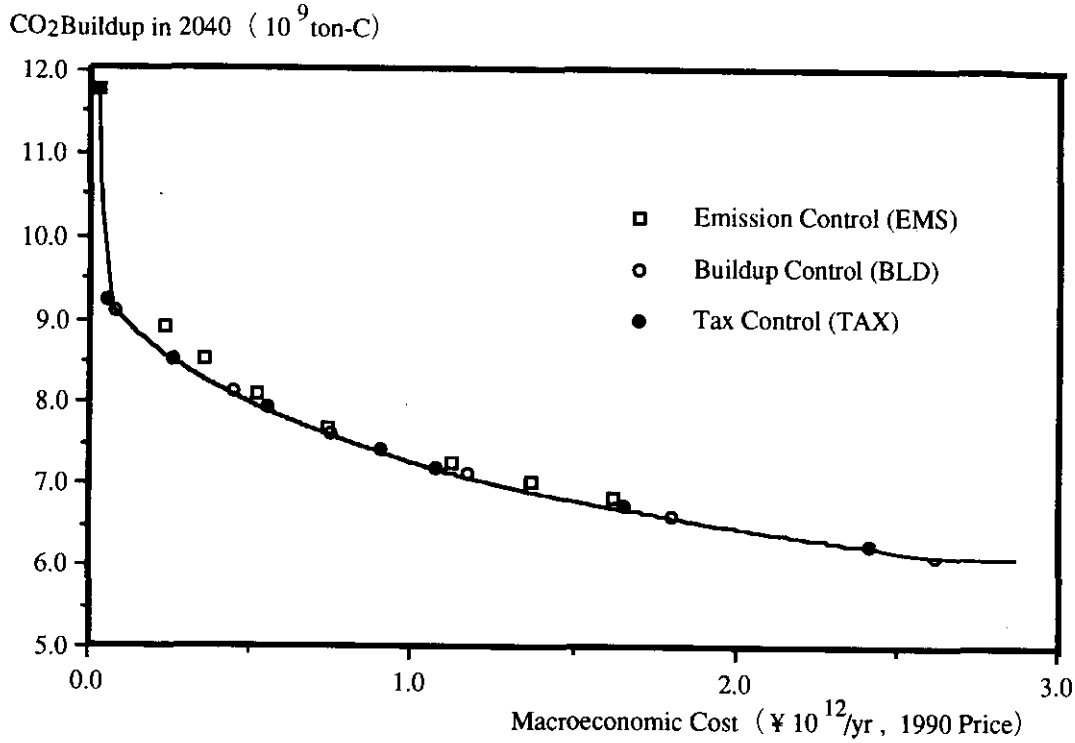


Figure 3.2 Reduction of CO2 Accumulation vs. Macro-economic Cost

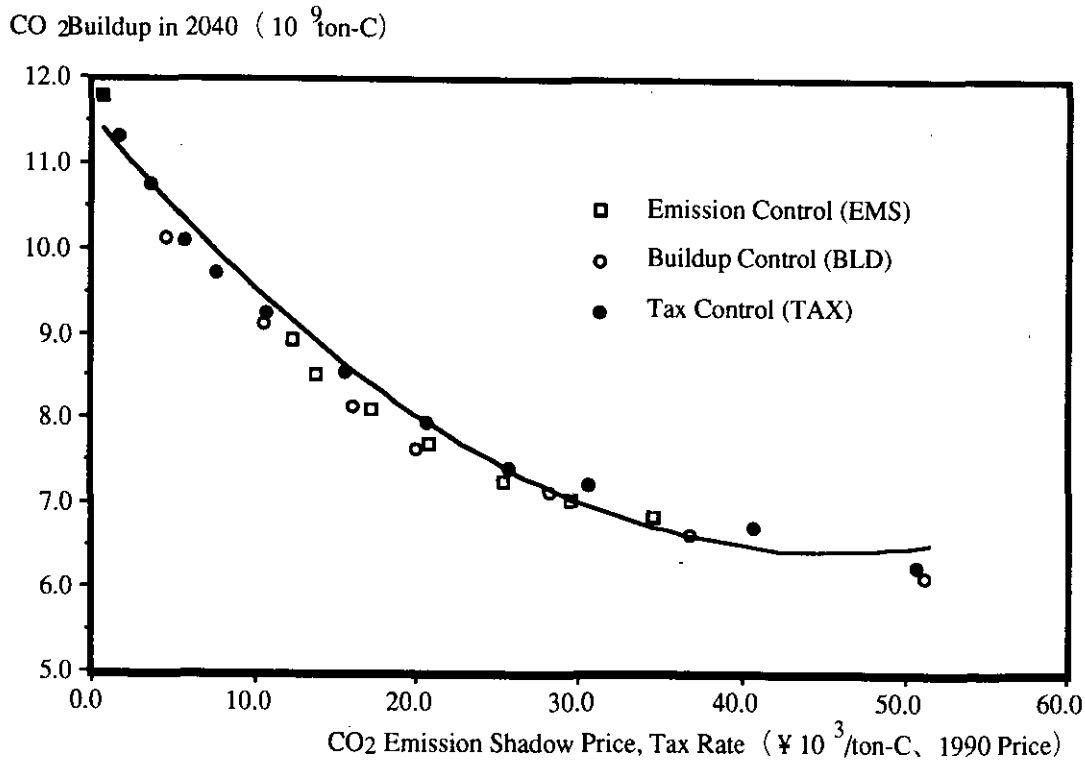


Figure 3.3 Reduction of CO2 Accumulation vs. the Tax Rate
(set equal to the Emission Shadow Price)

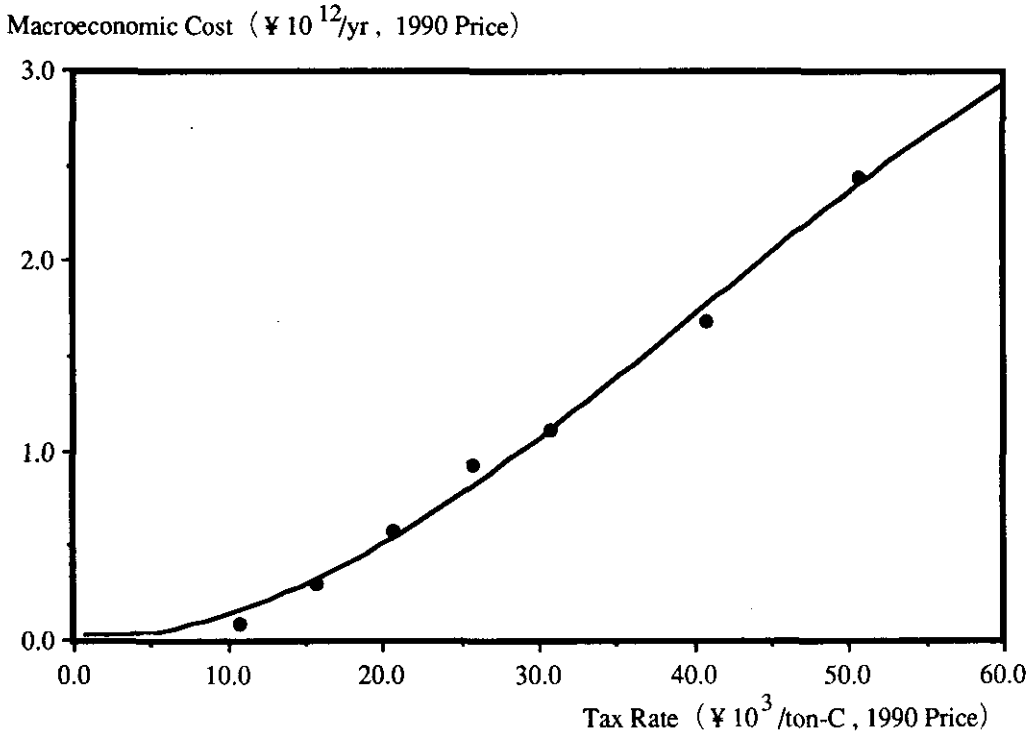
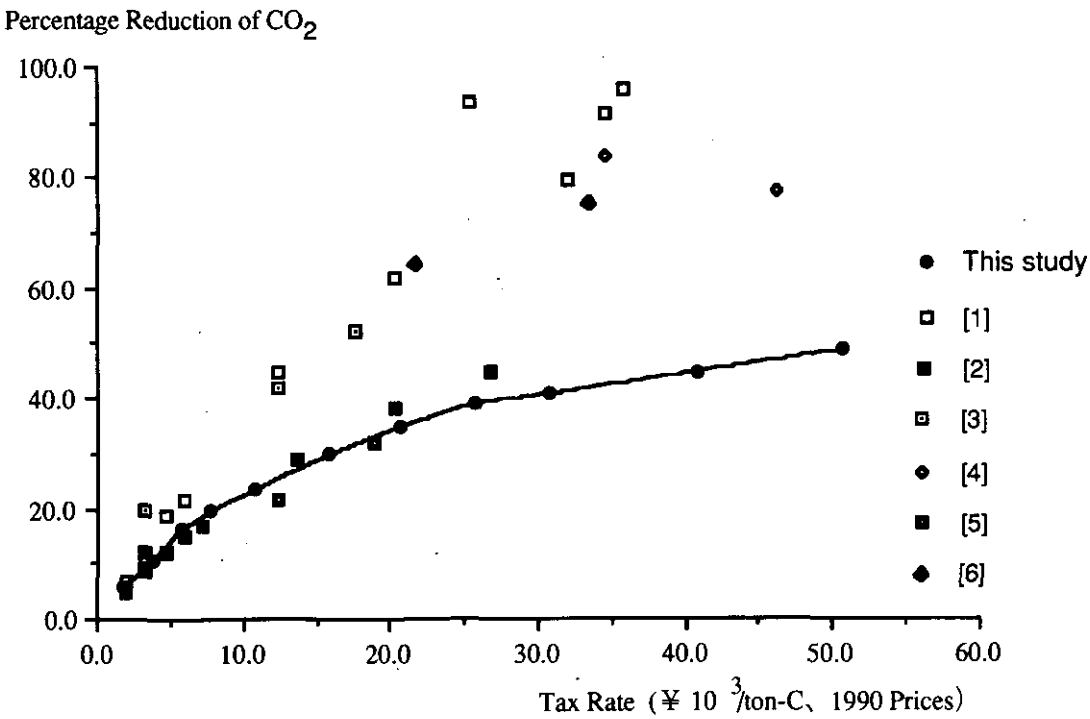


Figure 3.4 Macro-economic Cost vs. Tax Rate



Refs: [1] Nordhaus(1979), [2] Nordhaus and Yohe(1984), [3] Edmonds and Reilly(1983), [4] Manne and Richels(1990), [5] EC Study (1990), [6] Bodlund *et al.*(1989)
(Note: Exchange rate = ¥150/$)

Figure 3.5 Comparison among Several Studies of the Relation between CO2 Tax Rate and the Percentage Reduction in CO2 Emissions

4. CONCLUDING REMARKS

This study developed a dynamic market equilibrium model to evaluate the macro-economic impact of direct and indirect controls of CO2 emissions. Our model assumed that economic agents behave rationally and with perfect foresight. Therefore, our conclusions should be interpreted with some reservation. Real markets are not, in fact, as efficient as is assumed in the model and hence, we should be careful in applying our results directly to real problems. However, approaches that rely on the concept and analytical framework similar to this paper's are widely used, particularly by U.S. economists and can be quite useful to inquire the macro-economic consequences of CO2 emissions control policies

Our input data and premises are not necessarily perfect. It would be essential to continue examinations by repeatedly revising and updating them as our scientific and economic knowledges increase and deepen. However, our tentative results provide several suggestions to policy makers who are seriously considering CO2 emissions control policies. Also, what kind of policy should be implemented depends crucially upon the nature of the social welfare function. We hope that our analytical results may contribute to and encourage further discussions on the issue of global climate change.

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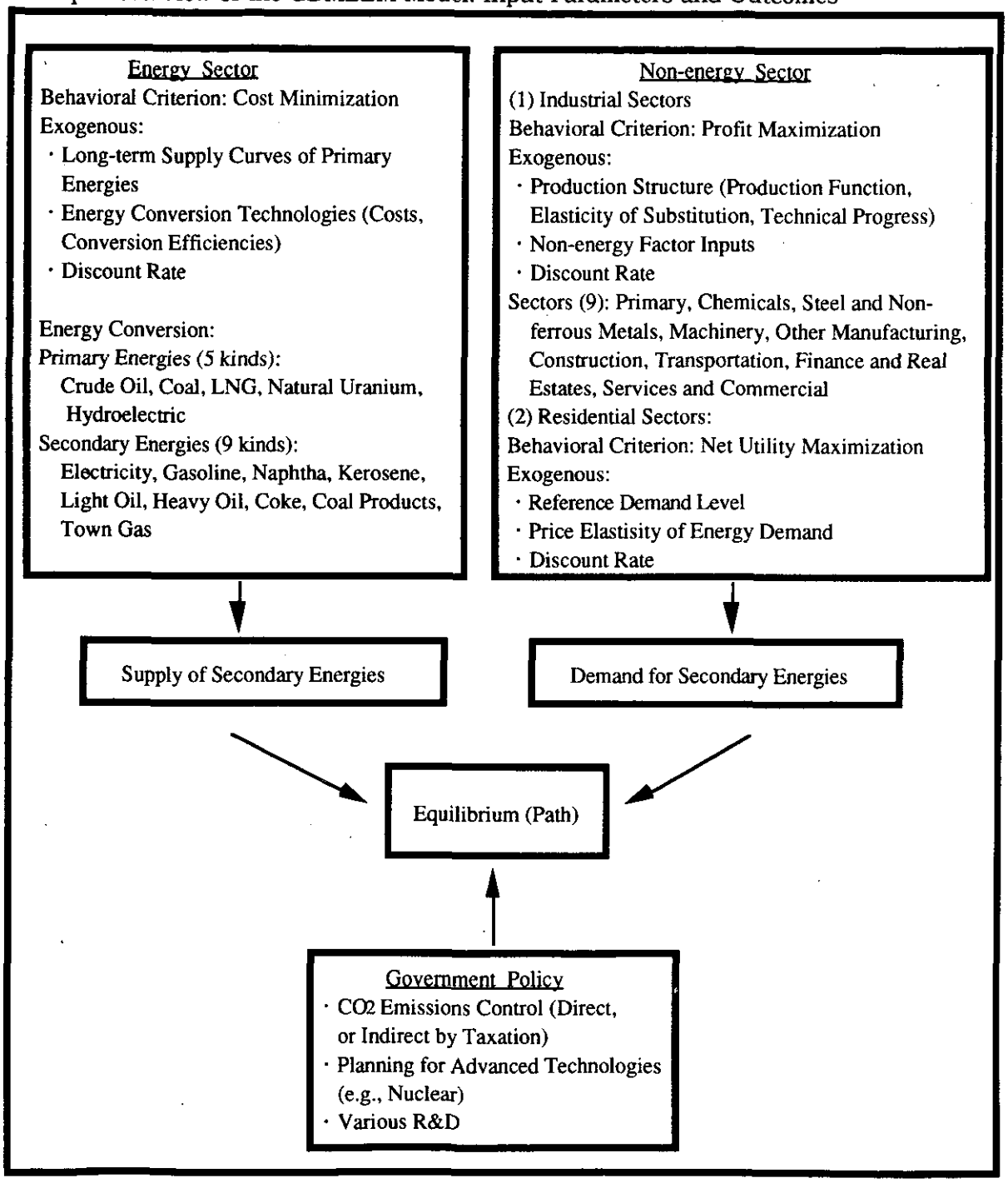
Appendix

Compressed View of the GDMEEM Model: Input Parameters and Outcomes