3.2 GLOBAL IMPACTS OF CARBON TAX
A SIMULATION ANALYSIS WITH A GLOBAL ECONOMETRIC MODEL*

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1. INTRODUCTION

In view of the growing importance of trade-off between world economic growth and global environment, a large scale econometric model was constructed by a research group since 1990 which covers 36 countries and regions with various economic and environmental variables.

This research project aims at analyzing the interdependence between economic growth, energy conservation and environmental protection through a consistent global system covering the various areas with different income and technology levels, resource endowment, and natural environment. As compared with recent similar studies on global environment, the present study puts more emphasis on sectoral details of production structure of industrial countries, since the energy and environmental issues are closely related to the production techniques and output components of the economy which are internationally linked to other economies through the flows of foreign trade and services. The growing needs for environmental costs, especially in industrial nations are likely to change its production technology and structure to become more efficient in energy intensity and its sectoral output components to be less energy-consuming. This type of analysis can be deepened by integrating such supply side analysis with price side analysis which deals with the price effects caused by the increase in environmental costs and the changes in comparative advantage in international market. In Japan, for instance, the share of steel in total industrial output fell significantly and that of electronics grew rapidly with the two oil price shocks in 1974 and 1980 as a turning point, mostly as a result of the changes in costs for energy and environment.

Considering these interdependent factors between different nations and different sectoral output and sectoral prices, it is obvious that a more general equilibrium type approach can deal with the complex nature of global environment and economic growth.

In view of the weakness of the present economic data for global analysis, however, our global model had to rely on a more simplified approach, a reduced form of multi-sectoral analysis, focusing on major industrial sectors related to environmental costs, especially on carbon dioxide. Sectoral interdependence between output and prices, however, is explicitly integrated for industrial countries so that the impact of carbon tax on CO2 consumption can be evaluated on sectoral basis in such countries.

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*The present study was financially supported by the National Institute for Environmental Studies and the Ministry of Education. The author is grateful to Profs. H. Ohba and H. Tamura, K. Harada, A.Kawakami, and O. Kobayashi for research advice and assistance. He is also indebted to Prof. S. Kinoshita for discussions on trade model and data.

2. THE MODEL

The present model was constructed as a joint project of the International University of Japan, the University of Tsukuba, the Nagoya University, and the Foundation for Advancement of International Sciences (FAIS). The environmental data basis was developed in collaboration with the Environmental Research Institute on the basis of IEA Statistics of Energy Balances. (See Moriguchi *et al* (1990) and OECD, IEA (1991))

The model covers 36 nations and regions, as shown below, with special reference to G7 nations of OECD and Asian newly industrialized countries, ASEAN member countries, and other major developing countries such as Brazil, China and India.

(CONTINENT)	(MEMBER COUNTRIES & REGIONS)
1. U.S.A.	U.S.A.
2. Western Europe (incl. Canada)	Canada, United Kingdom, France, Germany, Fed.Rep., Italy, Other Western Europe
3. Asia·Pacific D.C.	Japan, Australia, New Zealand
4. Eastern Europe	CIS (former Soviet), Other Eastern Europe
5. China, etc.	China, Other Asian Socialists
6. Middle East	Saudi Arabia, Iraq, Iran, Israel, Other Middle East
7. Africa	Egypt, Other Africa
8. Latin America	Mexico, Brazil, Argentine, Other Latin America
9. South East Asia	Korea, Taiwan, Hong Kong, Singapore, Philippines, Indonesia, Thailand, Malaysia, India, Pakistan, Other Asia

Total ... 29 nations + 7 regions = 36

In the system of the present model, each country model for developed countries (G7 or major seven countries of OECD) consists of three blocks: a) macro-economic block with fiscal monetary policy variables, b) sectoral output and price block, and c) CO_2 emissions block. For non-developed countries, including Asian NIES, each country has only a macro-economic block, but some of them are to be disaggregated as in the developed country model in the near future. The models for other regions are also simplified with only macro-economic variables. The above 36 country or regional models are linked by four trade flows matrices, i.e. 1) food, 2) raw materials, 3) fuels, and 4) manufactured products. Since our data basis on trade matrices has already been made

available, the fourth matrix on manufacturing will be further disintegrated into detailed commodity groups to facilitate more consistent sectoral analysis for industrial countries.

The present model is an expanded and improved version of the previous model which is known as Tsukuba-FAIS World Econometric Model (T-FAIS V). (See Shishido (1981)) The model had 24 countries and regions without sectoral breakdown for developed countries, but it had been widely used for macro-economic policy coordination among industrial countries and official development policy to developing countries. As compared with this previous version, the present model has three distinctive features.

First, the model eventually aims at fairly disaggregated, full-fledged multi-sector model with consistently specified foreign trade sectors, though, at the present stage, it is a reduced form type model, as mentioned earlier. The macro-economic block of the present model for seven industrial countries is integrated with the sectoral block with 21 manufacturing subsectors as shown in Table 1A. Each subsector has production and producer's price variables which are specified as below:

$$X_{ij} = f(\underset{(+)}{C_i}, \underset{(+)}{I_i}, \underset{(+)}{E_i}, \underset{(-)}{p_{xij}/p_i}) \qquad (1)$$

$$p_{ij} = f(\underset{(+)}{w_i}, \underset{(+)}{pm1i}, \underset{(+)}{pm2i}, \underset{(+)}{\rho_i}, \underset{(-)}{t}) \qquad (2)$$

$$(i = 1, \ldots 7)(j = 1, \ldots 21)$$

where X = output, C = consumption, I = investment,
E = exports, p_x = producer's price, w = wage rate,
p = GDP deflator, p_{m1}= import price of raw materials,
p_{m2}= import price of fuels, ρ= the rate of capacity
utilization of the economy, t = time trend.

Second, in order to link sectoral output to sectoral CO2 emissions, these sectoral categories are rearranged so as to conform with IEA's energy categories as shown in Table 1B. In this categories, CO2 emissions are explained by sectoral output or other macro-economic variables as specified below.

$$Q_{1ij} = f(\underset{(+)}{X_{ij}}, \underset{(-)}{t}) \qquad (3)$$

$$Q_{2ij} = f(\underset{(+)}{V_i} \text{ or } \underset{(+)}{I_i} \text{ or } \underset{(+)}{C_i}, \underset{(-)}{p_{eni}/p_{ci}}) \qquad (4)$$

where Q_1 = CO2 emissions in manufacturing
Q_2 = CO2 emissions in non-manufacturing
V = GDP, p_{en} = energy price, p_c = consumer price

A negative sign expected for t (time trend) means technical progress in emission control. Third, macro-economic block of the previous model has also been elaborated in the present version. In view of the growing importance of international linkage variables, capital transactions in the balance of payments, factor income transactions, and non-factor service transactions, and income transfers are explicitly endogenized so that private and official capital flows from surplus to deficit countries and related factor income flows are adequately analyzed. This improvement of the model is important from the point of view on global environment, since the huge amount financial and technical assistance is now urgently needed for promoting CO2 emissions control in developing countries. (See [5].)
Regarding CO2 equations in non-G7 countries CO2 emissions are regressed as below.

$$Q_i = f(V_i, p_{eni}/p_i) \quad (i = 1, \ldots 22) \qquad (5)$$
$$\quad (+) \quad (-)$$

where p = GDP deflator.

Table 1 Sectoral Classification for Output, Price and CO2 Emissions*

A. Output(X) & Price(p_x) Block	B. CO2 Emissions Block** (Final Use I.)
301 Food & Tobacco (31)	1. Iron & Steel (371)
302 Textiles & Apparels (321+322)	2. Chemicals (35)
303 Wood Products (331)	3. Non Ferrous (372)
304 Furnitures (332)	4. Ceramics (36)
305 Pulp & Paper (341)	5. Machinery (381, 382, 383, 384, 3843, 3845, 385)
306 Printing & Publishing (342)	6. Mining (GDP)
307 Chemicals (351+352)	7. Food (31)
308 Petroleum & Coal Products (353+354)	8. Paper & Publishing (341,342)
309 Rubber Products (355)	9. Wood & Furnitures (331,332)
310 Leather Products (323+324)	10. Construction (I)
311 Ceramics (36)	11. Textiles, leather (32,323,324)
312 Iron & Steel (371)	12. Other Manufacturing (39,355)
313 Non-Ferrous (372)	(Final Use II.)
314 Metal Products (381)	13. Transportation (GDP)
315 General Machinery (382)	14. Others (Household, etc.)(C)
316 Electrical Machinery (383)	
317 Automobiles (3843)	
318 Aircraft (3845)	
319 Other Transport Eq. (3841+3842+3844+3849)	
320 Precision Instruments (385)	
321 Other Manufacturing (39+356)	

* ... Figures in brackets mean ISIC code of U.N.

** ... I = fixed capital formation, C = private consumption

3. BASE LINE FORECAST AND POLICY SIMULATION OF CARBON

Before evaluating various impacts of macro-economic or structural policy measures, the present model was extrapolated for the period between 1990 and 2000. Exogenous assumptions for this forecast have been made to reflect the reality of the world environment as much as possible for the recent two years, but from 1992 on most exogenous variables were assumed to grow along the past trend in 1980's. The results of our forecasting in Table 2, therefore, should be regarded just as a basis of alternative policy scenarios and nothing more than that.

Three qualifications should also be added in reading the table. First, GDP in 1980 U.S. prices for the world does not fully cover the entire world economy, since minor socialist countries in Asia are excluded because of their data availability. However, they

represent only 0.17% of the world GDP. Second, socialist countries' income is NMP, stead of GDP, which is conceptually a little lower GDP in the Western concept. Third, CO2 emissions data does not cover other Africa, other Middle East, and other Asia.

In this table the world GDP grows at 3.1%, while CO2 at 2.1% for 1990 to 2000. This trend is broadly in accordance of the past trend in 1980's, except that the recent high economic growth of Asian NIES and ASEAN countries is assumed to level off.

Table 2 World GDP and CO2 Emissions in Base Line Forecasting

A. GDP (1980 billion $)

	1990	1995	2000	(average growth)
1. United States	3645.0	4047.4	4820.1	
(%)		2.1	3.6	2.9
2. Western Europe	4572.5	5116.5	5770.8	
(%)		2.3	2.4	2.4
3. Developed Asia-Pacific	1882.0	2176.7	2594.7	
(%)		3.0	3.6	3.3
4. Eastern Europe	1541.2	1749.7	1985.0	
(%)		2.6	2.6	2.6
5. China, etc.	685.1	928.5	1250.1	
(%)		6.3	6.1	6.2
6. Middle East	715.1	815.3	958.8	
(%)		2.7	3.3	3.0
7. Africa	224.3	244.2	258.6	
(%)		1.7	1.2	1.4
8. Latin America	1097.8	1290.4	1567.7	
(%)		3.3	4.0	3.6
9. South East Asia, etc.	1100.3	1398.2	1709.1	
(%)		4.9	4.1	4.5
10. World	15463.4	17766.9	20925.1	
(%)		2.8	3.3	3.1

B. CO2 Emissions (million ton)

	1990	1995	2000	(average growth)
1. United States	1411.3	1434.7	1490.1	
(%)		.3	.8	.5
2. Western Europe1/	648.4	628.2	626.7	
(%)		-.6	.0	-.3
3. Developed Asia-Pacific2/	344.9	349.7	372.2	
(%)		.3	1.3	.8
4. Eastern Europe	1483.2	1563.1	1647.8	
(%)		1.1	1.1	1.1
5. China, etc.	760.6	976.4	1246.7	
(%)		5.1	5.0	5.1
6. Middle East3/	85.4	98.3	111.4	
(%)		2.9	2.5	2.7
7. Africa4/	19.6	26.4	34.8	
(%)		6.2	5.6	5.9
8. Latin America	403.2	479.9	624.2	
(%)		3.5	5.4	4.5

9. South East Asia, etc.5/	378.0	513.0	652.3	
(%)		6.3	4.9	5.6
10. World	5534.6	6069.6	6806.2	
(%)		1.9	2.3	2.1

Note. 1/ 5 countries (Canada, U.K., France, Germany, Italy)
2/ Japan, Australia, New Zealand
3/ Iran, Iraq, Saudi Arabia
4/ Egypt only
5/ 4 Asia NIES, 4 ASEAN, and India and Pakistan

Especially noteworthy is the continuation of the falling share of CO2 emissions of the industrial countries and the rising share of the developing countries. In terms of CO2 intensity (= CO2/GDP), continuous improvement is noted for all industrial countries except Oceania, while deterioration is continuing in most of the developing countries.

Regarding the evaluation of individual country shown in Table 3, France shows the best performance in terms of both absolute level and intensity of CO2, with Japan ranking the second in terms of the intensity. Canada and Japan rank the second in terms of the rate of improvement in the intensity (see the last column).

Table 3 CO2 Emissions and CO2 Intensity of GDP

	1. CO2 (million ton)		2. GDP (1980 billion $)	
	1990	2000	1990	2000
Japan	263.4	266.9	1646	2295
U.S.	1411.3	1490.1	3645	4830
Canada	112.1	108.3	370	498
U.K.	154.4	157.1	674	901
France	86.8	71.5	815	1056
W.Germany	190.9	180.6	956	1224
Italy	104.1	109.3	556	712
Australia	75.9	99.1	208	268
New Zealand	5.7	6.2	28	32

	3. CO2 Intensity (CO2/GDP)*		
	1990	2000	2000/1990
Japan	0.160	0.116	0.725
U.S.	0.387	0.309	0.798
Canada	0.303	0.217	0.716
U.K.	0.229	0.174	0.760
France	0.107	0.068	0.636
W.Germany	0.200	0.148	0.740
Italy	0.188	0.154	0.819
Australia	0.365	0.370	1.014
New Zealand	0.203	0.194	0.956

Note : * million ton/billion $

How does the model predict the global consequence of adopting carbon tax by G7 nations in OECD? Here we concentrate on its global impact on growth and CO2 emissions. For the simplification of our exercise, we assumed an increase in the carbon tax rate by 20% for fossil fuel consumption in all the G7 nations. Other developed countries and developing countries remain unchanged in this tax rate

increase, but they are likely to be affected through their export changes and the inflationary impacts from their import prices.

Table 4 indicates the overall impacts of the carbon tax increase on various continental groups. Readers should be cautious of three points in evaluating its impact. First, the tax rate is increased gradually from 10% in 1990 to 20% in 1995 and 20% is sustained thereafter. Second, the positive price effect caused by the tax increase is likely to be offset partly by a contractionery income effect on aggregate demand caused by the tax increase. Third, the trade balance effect tends to be positive or negative depending on relative importance of price effect vs. income effect. For other countries than G7, the trade balance tends to deteriorate because of the shrinkage in the world imports.

The global result of carbon tax increase in terms of levels is shown in Table 4A and 4B.

As shown in Table 4C, a 20% increase in carbon tax rate of G7 reduces CO2 emissions by 1.3% for the world. The rates of reduction are 4.5% for the United States, 1.8% for the Western Europe (including non-G7 nations) and 1.0% for the developed Asia-Pacific. The corresponding fall in GDP is 0.8% for the world, 2.2% for the United States, 0.4% for the Western Europe, and 1.2% for the developed Asia-Pacific. For each individual country, the United States shows the largest decline of CO2 emission by 4.5% in 2000, while its GDP fell 2.2%, a half of CO2 emissions reduction. A similar, but less modest patterns in terms of response are observed for Canada, U.K., Germany, and Italy. GDP fell more slightly than did CO2 emissions. For France and Japan, however, the rates of reductions in CO2 emissions and GDP are almost the same, though Japan indicates higher values of about 1.3% for both variables. The Japanese relatively low response in CO2 emissions seems to be due to its low responsiveness to price changes in transportation sector and some rigidities in price behaviors.

Table 4 Carbon Tax Simulation on World GDP and CO2 Emissions

A. GDP

(1980 billion $)

		1990	1995	2000	(average growth)
1. United States		3630.8	3948.1	4724.4	
	(%)		1.7	3.7	2.7
2. Western Europe		4569.9	5098.6	5748.0	
	(%)		2.2	2.4	2.3
3. Developed Asia-Pacific		1878.9	2151.0	2564.8	
	(%)		2.7	3.6	3.2
4. Eastern Europe		1541.2	1750.2	1985.6	
	(%)		2.6	2.6	2.6
5. China, etc.		684.8	925.8	1246.9	
	(%)		6.2	6.1	6.2
6. Middle East		715.0	813.9	956.3	
	(%)		2.6	3.3	2.9
7. Africa		224.3	244.3	259.0	
	(%)		1.7	1.2	1.4
8. Latin America		1097.1	1284.8	1561.3	
	(%)		3.2	4.0	3.6
9. South East Asia, etc.		1099.9	1393.1	1701.5	
	(%)		4.8	4.1	4.5
10. World		15441.9	17609.6	20747.8	
	(%)		2.7	3.3	3.0

B. CO2 Emissions

(million ton)

		1990	1995	2000	(average growth)
1. United States		1405.0	1374.7	1423.8	
	(%)		-.4	.7	.1
2. Western Europe		646.1	617.4	615.4	
	(%)		-.9	-.1	-.5
3. Developed Asia-Pacific		344.6	346.4	368.5	
	(%)		.1	1.2	.7
4. Eastern Europe		1483.2	1563.4	1648.1	
	(%)		1.1	1.1	1.1
5. China, etc.		760.3	974.1	1244.0	
	(%)		5.1	5.0	5.0
6. Middle East		85.4	98.2	111.1	
	(%)		2.8	2.5	2.7
7. Africa		19.6	26.4	34.7	
	(%)		6.1	5.6	5.9
8. Latin America		402.8	476.2	619.3	
	(%)		3.4	5.4	4.4
9. South East Asia, etc.		377.9	511.4	649.7	
	(%)		6.2	4.9	5.6
10. World		5524.9	5988.1	6714.6	
	(%)		1.6	2.3	2.0

C. Percentage Deviation of Carbon Tax Simulation from Base Line Forecast

GDP

	1990	1995	2000
1. United States	-.390	-2.455	-2.189
2. Western Europe	-.057	-.351	-.395
3. Developed Asia-Pacific	-.166	-1.182	-1.152
4. Eastern Europe	.001	.026	.027
5. China, etc.	-.042	-.289	-.257
6. Middle East	-.013	-.169	-.261
7. Africa	-.003	.047	.145
8. Latin America	-.066	-.436	-.409
9. South East Asia, etc.	-.039	-.365	-.447
10. World	-.139	-.885	-.847

CO2

	1990	1995	2000
1. United States	-.444	-4.179	-4.454

2. Western Europe	-.358	-1.710	-1.800
3. Developed Asia-Pacific	-.100	-.935	-.971
4. Eastern Europe	.001	.018	.018
5. China, etc.	-.035	-.237	-.211
6. Middle East	-.004	-.136	-.301
7. Africa	-.031	-.212	-.245
8. Latin America	-.093	-.769	-.798
9. South East Asia, etc.	-.025	-.317	-.392
10. World	-.175	-1.343	-1.345

With respect to tax revenues, most G7 governments benefit 4 to 2% gains in 1990 to 1995, but those gains tend to be offset after 1995 because of growing deflationary impacts on their economies. In contrast, the trade surpluses of G7 nations tend to rise because of the fall in imports except Japan where its exports declined more than its imports.

The impacts of the carbon tax on the rest of the world also shows interesting changes in GDP and the trade balance.

Although there are no changes in tax policy in these countries, the fall in their GDP through the fall in their exports to G7 countries causes the reduction in CO2 emissions as well by almost the same percentage. For the same reason almost all the developing nations show the increase in their trade deficit. It is also noted that GDP of oil exporting countries are not significantly affected.

4. CONCLUDING REMARKS

As easily concluded from the above, the carbon tax increase can reduce CO2 emissions significantly at the relatively smaller cost of economic growth. Besides, the cost can be easily compensated through expansionary fiscal monetary policy of G7 nations, such as public spending for environmental policy, through which the loss of income in developing countries can also be compensated. The expected increase in CO2 emission caused by the latter policy will be insignificant as easily understood from the above simulation in which the CO2 emission intensity of G7 nations tend to decline structurally. In the longer perspective, however, the most serious problem would be the issue of CO2 emission control in the developing countries and East European countries under the appropriate aid program which is compatible with their sustainable growth in the global context. The present model is to be used for achieving this challenging target in the near future.

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