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MODELING AND EVALUATION OF KYOTO PROTOCOL FOR GLOBAL ENVIRONMENTAL PROTECTION FROM ECONOMICS VIEWPOINT

— Influence Analysis of USA for not Ratifying the Protocol —

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Abstract: In this paper we attempt to evaluate the influence of the decision of President Bush in March 2001 not to ratify the Kyoto Protocol. For this purpose we first build the evaluation model to analyze the influence to the other major developed countries. Then, we simulate some scenarios and analyze the competitiveness and profit of these countries in the international market. As the results it is found that the international emissions trading included in the Kyoto mechanisms is an effective means to achieve the emission reduction target. Furthermore, the influence of the United States for not ratifying the Kyoto Protocol to the other major developed countries is small from economics point of view under the international emissions trading. However, the influence to the developing countries is still to be investigated.

Keywords: Global environmental protection, Kyoto Protocol, carbon tax, emissions trading, global optimization, systems analysis.

1. INTRODUCTION

Kyoto Protocol was adopted in the third Conference of Parties (COP3) to the United Nations Framework Convention on Climate Change. In the Kyoto Protocol it was decided to direct emission reduction efforts to six types of greenhouse gases. The greenhouse gas emissions reduction target in the Protocol imposed on the developed countries is 5.2% from the 1990 level as a whole. For example, Japan is supposed to attain 94% of 1990 emissions, USA 93%, EU 92%, Russia 100%, during the period of 2008 to 2012. In order to attain this target, the use of Kyoto mechanisms (international emissions trading, joint implementation and the CDM: Clean Development Mechanism) is authorized. It had been discussed that the environmental tax would be effective to reduce the CO_2 emission (Gaskins and Weyant, 1993). In fact, the environmental tax or carbon tax has been imposed in Northern Europe and it seems that these taxes work effectively.

In March 2001 president Bush announced that the United States would not ratify the Kyoto Protocol. Since the United States emit the largest amount of CO_2 in the world, the influence of this decision to the other developed countries might be quite big from the economics viewpoint.

This paper tries to find effective economic policies for the developed countries to achieve the CO_2 emission reduction target even when the United States would not ratify the Kyoto Protocol. For this purpose we first build the evaluation model to analyze the influence of the United States to the other major developed countries. Then, we simulate and analyze some scenarios and analyze the competitiveness and profit of these countries in the international market when the United States would not ratify the Kyoto Protocol.

2. EVALUATION MODEL

2.1 *Framework*

The foregone models to evaluate the CO_2 mitigation policy are classified into 2 types. First type is energy economic model. Typical models

of energy economic model are GRAPE, MS-MRT etc. Since this model includes the adjustment of energy technology, this model focuses on long run term. Therefore, this type is not applied in this paper. Second type is an applied general equilibrium model, and there are G-CUBED, GTAP (Hertel, 1997) and so on as examples of this model. The evaluation model proposed in this paper can be regarded as a kind of applied general equilibrium model. Applied general equilibrium model includes multiple economic sectors within the structure. Then this model focuses on the interactions of firms and consumers in various sectors and industries, and allows for inter-industry interactions and international trade in non-energy goods (Energy Journal, 1999). However, foregone application does not incorporate the industry's behavior relevant to CO_2 emissions reduction sufficiently. The proposed model reduces this behavior to CO_2 cost minimization problem and incorporates it into the framework of applied general equilibrium model.

In this model, following conditions are given.

1) The object of analysis are five major countries: Japan, United States, United Kingdom, France and Germany.
2) Five major countries introduce the carbon tax. Five major countries and Russia join in international emissions trading market. Here, Russia is regarded as the country of emission rights supplier.
3) The transactions are divided into domestic transactions, trades among 5 major countries (international trades), trades between 5 major countries and the rest of the world (ROW), and trades among ROW.
4) International trades are assumed Cournot competition in the oligopoly market.
5) Trades between 5 major countries and ROW, and trades among ROW handle as under the given condition.
6) The industry of every country is classified into 10 sectors as shown in Table 1.

This model consists of profit maximization problem and subproblems. Profit maximization problem is based on input-output analysis (Leontief, 1970; Tamura, et al., 1998; Tamura and Isida, 1985) and expresses the profits maximization behavior of each country. Also subproblems express domestic transactions, international trades, and the CO_2 cost, which describes the cost to reduce (or fix) CO_2 and the cost for paying carbon tax.

2.2 *Profit maximization problem*

In each country, consider the following profit maximization problem.

Table 1. Classification of industrial sectors

Sec.1	Agriculture, Forestry and Fishery /Food product
Sec.2	Fiber /Pulp, wooden goods
Sec.3	Chemistry product /Petroleum product
Sec.4	Steel /Nonferrous metal /Metal
Sec.5	General machinery /Electricity machinery /Precision machinery
Sec.6	Other manufacturing industry
Sec.7	Construction
Sec.8	Transportation
Sec.9	Service
Sec.10	Others

$$\underset{\mathbf{x},\mathbf{v}}{\text{maximize}} \quad \mathbf{p_s}(\mathbf{x},\mathbf{v})\mathbf{x} - \mathbf{p_d}(\mathbf{x},\mathbf{v})(\mathbf{A}-\mathbf{M})\mathbf{x} - k(\mathbf{x}) \tag{1}$$

$$\text{subject to} \quad (\mathbf{I}-\mathbf{A}+\mathbf{M})\mathbf{x} \leq \mathbf{d}(\mathbf{p_d}) + \mathbf{w} \tag{2}$$

where

$\mathbf{x}$	:	output vector
$\mathbf{v}$	:	value-added vector
$\mathbf{p_s}(\cdot)$	:	price vector of the domestic supply
$\mathbf{p_d}(\cdot)$	:	price vector of the domestic demand
$\mathbf{A}$	:	input-output coefficient matrix
$\mathbf{M}$	:	import coefficient matrix
$\mathbf{d}(\cdot)$	:	domestic final demand vector
$\mathbf{w}$	:	export vector
$k(\cdot)$	:	CO_2 cost

First term of the objective function (1) denotes gross sales, the second term intermediate input cost, and the third term the cost associated with CO_2. Constraint equation (2) is based on the output determination of input-output analysis and shows the restriction of output.

2.3 *Subproblems*

Changes of Domestic Final Demand

Changes of the domestic final demand is written as

$$d_i = d_{i0}(1 - \epsilon_i \frac{p_{d_i} - p_{d_{i0}}}{p_{d_{i0}}}) \tag{3}$$

where

d_i	:	domestic final demand of sector i
d_{i0}	:	initial quantity of the domestic final demand of sector i
ϵ_i	:	price elasticity of demand for the output of sector i
p_{d_i}	:	price of the domestic demand for output of sector i
$p_{d_{i0}}$	:	price of the initial domestic demand for the output of sector i

p_{d_i} is element of the price vector p_d.

$$\mathbf{p_d} = \mathbf{p_d}(\mathbf{A}-\mathbf{M}) + \mathbf{v} + \mathbf{k} \tag{4}$$

where

$\mathbf{k}$: CO_2 cost per 1 unit vector

Changes of Export

Since export competition is supposed as Cournot competition in this paper, export w is determined by the following model.

$$\underset{g_i}{\text{maximize}} \quad p_i^a(w_i)w_i - c_i w_i \tag{5}$$

$$\text{subject to } p_i^a(w_i) = a - b(w_i + w_i^a) \tag{6}$$

$$c_i = p_{d_i}(A_i - M_i) + k_i \tag{7}$$

$$w_i \geq 0 \tag{8}$$

where

w_i : export of sector i
$p_i^a(\cdot)$: import demand function of sector i
c_i : coefficient of cost function of sector i
a : constant term of import demand function
b : coefficient of import demand function
w_i^a : sum of export of sector i in the rest of the countries

First term of equation (5) denotes gross sales in export and second term is total cost in export. Equation (6) is import demand function and equation (7) is the coefficient of cost function.

Since subjects of analysis are five major countries, for example, export of sector i in Japan for United States is found as follows:

$$w_{ui}^j = \frac{a_{ui} - 4c_{ji} + c_{ei} + c_{fi} + c_{gi}}{5b_{ui}} \tag{9}$$

where

w_{ui}^j : export of sector i from JPN to USA
a_{ui} : constant term of import demand function associated with sector i in USA
b_{ui} : coefficient of import demand function associated with sector i in USA
c_{ji} : coefficient of cost function associated with sector i in JPN
c_{ei} : coefficient of cost function associated with sector i in UK
c_{fi} : coefficient of cost function associated with sector i in Fr.
c_{gi} : coefficient of cost function associated with sector i in Ger.

Introduction of Carbon Tax

Suppose for any output level $\bar{x_i}$, the cost minimization problem associated with CO_2 is written as

$$\underset{s_i,t}{\text{minimize}} \sum_{i=1}^{n} \{ \int_0^{s_i} f_i(s)ds + (1 - s_i)t_i \} r_i \bar{x_i} \tag{10}$$

$$\text{subject to } \sum_{i=1}^{n} (1 - s_i) r_i \bar{x_i} \leq T \tag{11}$$

where

s_i : CO_2 reduction rate of sector i
t : carbon tax rate
$f_i(\cdot)$: CO_2 reduction cost function of sector i
r_i : CO_2 emission coefficient of sector i
T : CO_2 emission target

This model shows supply-demand adjustment by updating the output in profit maximization problem.

Participation in International Emissions Trading

We assume the universal carbon tax model. In the universal carbon tax model, common carbon tax rate is imposed on every country under the constraint of total CO_2 emissions target. Here, carbon tax model and emissions trading model are related with duality. This duality represents that the emissions right price is equivalent to the common carbon tax rate. By using this duality, the differences between CO_2 emissions of each country in the universal carbon tax model and CO_2 emissions targets of each country can be regarded as the emissions traded in the international market. Therefore, the universal carbon tax model is reduced to the mixture of introduction of carbon tax and participation in the international emissions trading.

2.4 *Steps of Procedure*

Solving the cost minimization problem (10), following equation is obtained.

$$f_i(s_i) = t \tag{12}$$

CO_2 reduction rate is determined by this equation. Steps of a procedure in the model to evaluate the introduction of carbon tax are shown as follows:

<Step 1>
Given carbon tax rate in each country, CO_2 cost is calculated by using equation (10).

<Step 2>
Given initial value of value-added, from equations (3),(4), the domestic final demand $\mathbf{d}(\mathbf{p_d})$ is obtained. From equations (4),(7),(9), export $\mathbf{w}$ are obtained.

<Step 3>
Solve profit maximization problem (1),(2) in each country. If the calculated $\mathbf{v}$ is equaled to the initial values, then go to Step 4. If not, go to Step 2 and update $\mathbf{v}$.

<Step 4>
If CO_2 reduction rates are less than or equal to the reduction targets in every country, then the operation is over. If not, go to Step 1.

3. DATA

3.1 *Production and Demand Data*

Input-output table of each country revised from the international input-output table is applied to the production data. Import demand function is estimated by using the trade statistics of each country. Price elasticity of final demand, income elasticity of final demand and price elasticity of export to all but five countries are obtained as shown in Tables 2 and 3.

3.2 *Efficiencies of CO_2 Emission and CO_2 Reduction*

CO_2 emissions coefficient is calculated by using fuel consumption rate data and input-output table as shown in Table 4 is obtained. Table 4 indicates that

1) Japan and France have high energy efficiency.

2) Sectors 3 and 4 discharge much CO_2 per 1 unit.

3) There is large inter-industrial gap with respect to the efficiency of CO_2 emissions.

CO_2 reduction cost functions are estimated by using marginal carbon reduction costs based on the United States Department of Energy calculations, and international input-output table.

$$\text{JPN} : f^j(s_j) = 314.9(s_j + 0.846)^{2.319} \quad (13)$$

$$\text{USA} : f^u(s_u) = 314.9(s_u + 0.545)^{2.319} \quad (14)$$

$$\text{UK} : f^e(s_e) = 314.9(s_e + 0.682)^{2.319} \quad (15)$$

$$\text{Fr.} : f^f(s_f) = 314.9(s_f + 0.858)^{2.319} \quad (16)$$

$$\text{Ger.} : f^g(s_g) = 314.9(s_g + 0.776)^{2.319} \quad (17)$$

Table 2. Elasticity of final demand

Sector	Price elasticity	Income elasticity
1	-0.2562	0.4949
2,3	-0.9013	0.8439
4,5,6,7	-1.1880	1.2402
8,9	-0.6233	1.0753
10	-0.7617	0.9908

Table 3. Price elasticity of export to all five countries

	Price elasticity
JPN	-0.24
USA	-0.31
EU	-0.45

Table 4. CO_2 emission coefficient (ton carbon/unit)

	JPN	USA	UK	Fr.	Ger.
Sec.1	1.057	3.623	1.791	1.218	1.856
Sec.2	1.241	4.253	2.103	1.431	2.179
Sec.3	5.808	19.905	9.838	6.694	10.196
Sec.4	3.328	2.875	3.163	2.040	1.299
Sec.5	0.871	1.088	1.241	0.708	0.892
Sec.6	1.600	3.806	2.743	2.172	2.389
Sec.7	1.107	4.346	3.124	1.011	2.122
Sec.8	1.565	6.146	4.418	1.429	3.000
Sec.9	0.623	2.445	1.757	0.568	1.193
Sec.10	1.428	5.609	4.031	1.304	2.738

4. POLICY DESIGN AND ITS EVALUATIONS

4.1 *Policy Scenarios*

We postulate four scenarios as follows:

<Scenario 1>
Five major developed countries (Japan, USA, UK, France and Germany) introduce carbon tax. Here, each country determines its own carbon tax rate so that each emission target can be achieved.

<Scenario 2>
Five major countries and Russia join the international emissions trading. At the same time, five major countries introduce carbon tax with the same tax rate as the international emissions trading price.

<Scenario 3>
Four major countries without USA introduce carbon tax. Each country determines its own carbon tax rate so that each emission target can be achieved.

<Scenario 4>
Four major countries without USA and Russia join the international emissions trading. At the same time, these four major countries introduce carbon tax with the same tax rate as the international emissions trading price.

4.2 *Scenario Analysis*

Table 5 shows carbon tax rate in each country for each scenario. From this table we can find the evaluation results as follows:

1) In Scenario 1 USA could attain the emission target with relatively low carbon tax rate. This is because USA could reduce CO_2 emissions further.

2) By comparing Scenarios 1 and 3 the necessary carbon tax rate to achieve the emission target is the same whether USA would ratify the Protocol or not.

Table 5. Carbon tax rate ($/ton carbon)

Scenario	JPN	USA	UK	Fr.	Ger.
1	239.1	90.9	153.3	258.0	197.8
2	88.4	88.4	88.4	88.4	88.4
3	239.0	0.0	153.4	258.0	197.8
4	12.6	0.0	12.6	12.6	12.6

3) By comparing Scenarios 2 and 4 the international emissions trading price for Scenario 4 is about 1/7 of that for Scenario 3. This is because without USA four major countries could buy more emissions right from Russia and they could attain the emission target without reducing CO_2 emission so much.

In Figure 1 amount of CO_2 emission in each country and its total sum are shown for each scenario. The amount of CO_2 emission in USA is about 2.5×10^9 ton, and this is about 65% of the total sum of five major developed countries. The emission reduction target of CO_2 for USA is about 1.8×10^8 ton and this amount is almost equal to the amount of CO_2 emission in France. If USA would not ratify the Kyoto Protocol, the total sum of CO_2 emission would increase this amount. This is, of course, undesirable from the viewpoint of global environmental protection. In the following of this paper we will analyze the influence of USA for not ratifying the Protocol to the other major developed countries from the viewpoint of economics.

Tables 6, 7 and 8 shows export share for the cases without carbon tax, with carbon tax (Scenario 3) and with carbon tax and international emissions trading (Scenario 4), respectively when the United States would not ratify the Kyoto Protocol. From these tables we can find the evaluation results as follows:

1) By comparing Tables 6 and 7 for the United States the export share among five major countries would increase in Scenario 3 if the United States would not ratify the Kyoto Protocol, but the amount of increase is not so much, that is, 1.2% in total. The amount of increase in each sector is different from sector to sector.

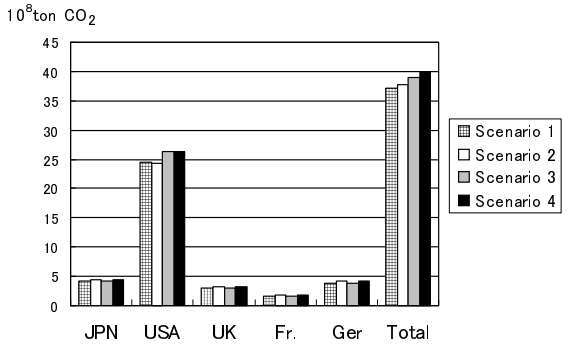

Fig. 1. Amount of CO_2 emission in each country and total sum

Table 6. Export share before taxation

	JPN	USA	UK	Fr.	Ger.
Sec.1	2.9	45.8	15.7	5.9	29.7
Sec.2	7.4	14.6	17.6	28.5	31.9
Sec.3	13.5	15.5	19.3	19.3	32.4
Sec.4	11.0	15.0	14.4	17.5	32.1
Sec.5	27.9	27.2	10.1	9.0	25.8
Sec.6	29.2	19.8	8.8	13.1	29.1
Sec.7	0.0	0.0	0.0	0.0	0.0
Sec.8	32.7	27.6	0.0	0.0	39.7
Sec.9	0.0	55.4	17.3	14.5	12.8
Sec.10	0.0	32.1	4.4	60.7	2.8
Total	24.1	25.0	10.9	12.2	27.8

Table 7. Export share for Scenario 3

	JPN	USA	UK	Fr.	Ger.
Sec.1	2.9	48.7	15.6	4.7	29.1
Sec.2	7.4	15.4	17.6	28.3	31.3
Sec.3	13.9	18.0	19.4	18.1	30.6
Sec.4	10.6	15.7	14.2	27.1	32.4
Sec.5	27.2	27.9	10.1	9.0	25.8
Sec.6	29.1	20.8	8.8	12.8	28.5
Sec.7	0.0	0.0	0.0	0.0	0.0
Sec.8	32.8	28.8	0.0	0.0	38.4
Sec.9	0.0	59.1	15.9	14.1	10.9
Sec.10	0.0	33.5	4.1	59.8	2.6
Total	23.8	26.2	10.8	11.9	27.3

Table 8. Export share for Scenario 4

	JPN	USA	UK	Fr.	Ger.
Sec.1	2.9	46.0	15.7	5.8	29.6
Sec.2	7.4	14.8	17.5	28.5	31.8
Sec.3	13.6	15.7	19.2	19.3	32.2
Sec.4	11.0	15.1	14.4	27.5	32.0
Sec.5	27.9	27.2	10.1	9.0	25.8
Sec.6	29.2	19.9	8.8	13.0	29.1
Sec.7	0.0	0.0	0.0	0.0	0.0
Sec.8	32.8	27.7	0.0	0.0	39.5
Sec.9	0.0	55.8	17.1	14.4	12.7
Sec.10	0.0	32.2	4.4	60.7	2.7
Total	24.1	25.1	10.9	12.2	27.7

Table 9. Influence to profit in Scenario 3

	JPN	USA	UK	Fr.	Ger.
Sec.1	98.7	99.6	98.3	98.1	98.1
Sec.2	97.0	100.1	97.1	96.8	96.3
Sec.3	90.1	99.6	92.0	87.5	87.6
Sec.4	93.7	99.7	96.1	95.3	97.0
Sec.5	96.4	99.9	97.4	98.4	97.7
Sec.6	95.4	99.9	95.9	94.8	95.4
Sec.7	96.9	99.6	94.9	97.7	95.3
Sec.8	97.2	99.7	96.5	97.3	96.4
Sec.9	97.7	100.0	96.4	98.4	97.0
Sec.10	98.7	99.6	94.8	99.7	95.6
Total	96.1	99.8	96.0	96.4	95.7

2) By comparing Tables 6 and 8 for the United States the amount of increase of the export share is only 0.1% in total.

Table 10. Influence to profit in Scenario 4

	JPN	USA	UK	Fr.	Ger.
Sec.1	99.9	99.9	99.5	99.9	99.9
Sec.2	99.8	100.0	99.8	99.8	99.6
Sec.3	99.3	99.8	99.1	99.2	99.1
Sec.4	99.4	100.0	99.6	99.7	99.7
Sec.5	99.8	100.0	100.0	99.9	99.8
Sec.6	99.6	99.7	99.7	99.6	99.7
Sec.7	99.8	100.0	99.5	99.8	99.6
Sec.8	99.8	100.0	100.2	99.8	99.6
Sec.9	99.8	100.0	99.5	99.8	99.8
Sec.10	99.9	99.9	99.4	100.0	99.8
Total	99.7	99.9	99.6	99.7	99.6

3) By comparing Tables 7 and 8 for four major countries without USA they could get better export share in Scenario 4. By comparing Tables 6 and 8 for four major countries without USA they could get almost the same export share. This result implies that even if the United States would not ratify the Protocol, four other major countries could keep the international competitiveness in the market attaining the emission target with carbon tax and international emissions trading.

Tables 9 and 10 shows influence of carbon tax and/or international emission trading to profit in Scenarios 3 and 4, respectively, where it is assumed that the profit obtained before the taxation is equal to 100. From these tables we can find the evaluation results as follows:

1) When four major countries join the international emissions trading as in Scenario 4, they could get almost the same profit as the profit obtained before the taxation.
2) In Scenario 3 the decrease of profit affected by the carbon tax is very much dependent on the sector, but by using the international emission trading in Scenario 4 the decrease of profit is getting very small and the difference among the sectors is also very small.

5. CONCLUDING REMARKS

In this paper the evaluation model is developed to analyze the influence of the United States for not ratifying the Kyoto Protocol to the other major developed countries from the view point of economics. Then, we simulated four scenarios and analyzed the international competitiveness and profit in each country where we postulated that the emission reduction targets for four major developed countries are unchanged whether the United States would ratify the Protocol or not. From the analysis we have found the following results:

1) The international emissions trading price is getting 1/7 if the United States would not ratify the Protocol. This is because without USA four major countries could buy more emissions right from Russia and they could attain the emission reduction target without reducing CO_2 emissions so much.
2) The influence of the United States for not ratifying the Protocol to the other major countries is small from the economics point of view if the international emissions trading is adopted among four major countries and Russia besides imposing the carbon tax with the same tax rate as the international emissions trading price.
3) International emissions trading is authorized as one of the Kyoto mechanism and it is found that this is an effective means to attain the emission reduction target of each country without affecting the influence to economies in each country so much.

For further research we need to analyze the influence of the United States leaving the Protocol on reducing emissions in the developing countries which might be quite big.

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