Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Modeling and Policy Assessment of Carbon Tax and Emissions Trading for Preserving Global Environment

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Abstract: In this paper we formulate a dynamic model of a profit maximization problem for assessing quantitatively how the policy of carbon tax and emissions trading would be effective to achieve the targeted reduction of the Kyoto Protocol. Furthermore, we evaluate the influence of carbon tax and emissions trading on the economy in industry in a long-term view.

1. INTRODUCTION

The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC, 2003). Countries that ratify this protocol commit to reduce their emissions of CO_2 and five other greenhouse gases (GHG), or engage in emissions trading if they maintain or increase emissions of these gases (Hertel, ed., 1993).

Governments are separated into two general categories: developed countries, referred to as Annex 1 countries (who have accepted GHG emission reduction obligations and must submit an annual greenhouse gas inventory); and developing countries, referred to as Non-Annex 1 countries (who have no GHG emission reduction obligations but may participate in the Clean Development Mechanism (CDM)).

The treaty was negotiated in Kyoto, Japan in December 1997, and the agreement came into force on February 16, 2005 following ratification by Russia on November 18, 2004. As of December 2006, a total of 169 countries and other governmental entities have ratified the agreement (representing over 61.6% of emissions from Annex 1 countries). Notable exceptions include the United States and Australia. Other countries, like India and China, which have ratified the protocol, are not required to reduce carbon emissions under the present agreement despite their relatively large populations.

By 2008-2012, Annex 1 countries have to reduce their GHG emissions by an average of 5% below their 1990 levels (for many countries, such as the EU member states, this corresponds to some 15% below their expected GHG emissions in 2008). While the average emissions reduction is 5%, national targets range from 8% reductions for the European Union to a 10% emissions increase for Iceland. Reduction targets expire in 2013 (Wikipedia, 2007).

Japanese government is conservative to introduce carbon tax, emissions trading between various industries in Japan and also between countries in the world, to feedback the carbon tax revenue for reducing the greenhouse gas emissions. This is because the industrial circles in Japan are opposing against these policies for fear that the economic competitiveness is decreasing.

In this paper, we consider the carbon tax and the emissions trading among 5 developed countries and Russia as an emissions permit supplier in order to meet the CO_2 emissions reduction target, and evaluate the economic influence on the industry in each country.

2. MODELING FOR POLICY ASSESSMENT

We construct a dynamic version of the mathematical model described in Akazawa, et al. (2002). The objective countries are Japan, United States, United Kingdom, France, and Germany as shown in the model summarized in **Fig. 1**. In Fig. 1 solid line between two countries shows the existence of commodities trade, and the dotted lines show emissions trading. Russia is added as an emissions permits supplier in the emissions trading. The industry of these countries is classified into 10 sectors as shown in **Table 1**. This model consists of a profit maximization problem and sub-problems. The former problem is based on the dynamic

978-1-1234-7890-2/08/$20.00 © 2008 IFAC

10.3182/20080706-5-KR-1001.0599

input-output analysis (Leontief, 1970; Tamura, et al., 2001) and expresses the profit maximization behavior of each country, which introduces the carbon tax and the emissions trading to meet the emissions reduction target. The latter problems express domestic transaction, international trades, and the CO_2 cost, which describes the cost to reduce CO_2 and the cost for paying carbon tax.

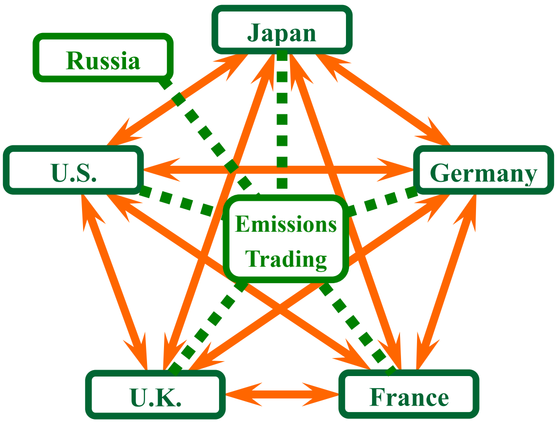


Fig. 1. International input-output model among 5 developed countries, and Russia as an emissions permits supplier

Table 1. Classification of industrial sectors

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

A dynamic model of the profit maximization problem is written as,

$$\underset{x_t, v_t}{\text{Maximize}} \quad \sum_{t=1}^{n} \{ p(x_t, v_t) x_t - p(x_t, v_t)(A - M) x_t - k(x_t) \} \qquad (1a)$$

$$\text{subject to} \quad (I - A + M + B) x_{t-1} - B x_t \geq d(p_{t-1}) + w_{t-1} \qquad (1b)$$

$$t = 1, 2, \ldots, n$$

where, $p(*)$ denotes a domestic price vector, x denotes an output vector, v denotes a value-added vector, A denotes an input-output coefficient matrix, M denotes an import coefficient matrix, B denotes a capital coefficient matrix, $k(*)$ denotes a CO_2 cost, $d(*)$ denotes a domestic final demand vector, and w denotes an export vector.

Transition of the domestic final demand in time is written as,

$$d_{i,t} = d_{i,t-1} \left(1 + \varepsilon_i \frac{p_{i,t} - p_{i,t-1}}{p_{i,t-1}} \right) \qquad (2)$$

where, d_i denotes the domestic final demand of sector i, ε_i denotes a price elasticity of the domestic output of sector i, and p_i denotes a price of the domestic demand of sector i.

In this paper, the export competition is supposed as Cournot competition, so export is determined as follows:

$$\underset{w_{i,t}}{\text{Maximize}} \quad p_i^a(w_{i,t}) w_{i,t} - c_{i,t} w_{i,t} \qquad (3a)$$

$$\text{subject to} \quad p_i^a(w_{i,t}) = a - b(w_{i,t} + w_{i,t}^a) \qquad (3b)$$

$$c_{i,t} = p_{i,t}(A_i - M_i) + k_{i,t} \qquad (3c)$$

$$w_{i,t} \geq 0 \qquad (3d)$$

where p_i^a denotes an import demand function of sector i, w_i denotes an export of sector i, a denotes a constant term of an import demand function, b denotes a coefficient of an import function, and w_i^a denotes a sum of export of sector i in the rest of the countries.

Fig. 2 shows CO_2 marginal reduction cost with respect to CO_2 reduction rate. In general, the more energy efficiency is improved, the more marginal reduction cost of CO_2 emissions is increased (Energy Information Administration, 2003). In Fig. 2 t_0 denotes the CO_2 marginal reduction cost at the present time. If the carbon tax rate of t_1 was imposed, each economic unit would reduce CO_2 up to the reduction rate of s_1. At this point CO_2 marginal reduction cost would be equal to the carbon tax rate, since each economic unit would minimize the CO_2 cost that is composed of the cost for reducing CO_2 and the cost for carbon tax.

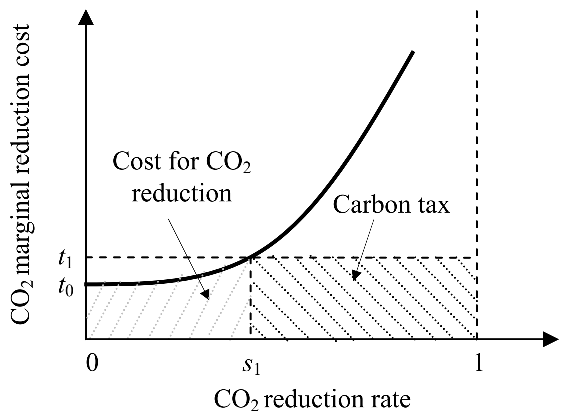


Fig. 2. CO_2 cost composed of cost for CO_2 reduction and carbon tax.

Hence, the total CO_2 cost is described as

$$k(\bar{x}) = \min_{t_t, s_{i,t}} \sum_{i=1}^{10} \left\{ \int_0^{s_{i,t}} f(s_i) ds_i + (1 - s_{i,t}) t_t \right\} r_i \bar{x}_i \tag{4a}$$

$$\text{subject to} \quad \sum_{i=1}^{10} (1 - s_{i,t}) r_i \bar{x}_i \le T_t \tag{4b}$$

where t denotes carbon tax, $s_{i,t}$ denotes CO_2 reduction rate in the i-th sector at time t, $f(*)$ denotes CO_2 reduction cost function, r_i denotes CO_2 emission coefficient in the i-th sector and T_t denotes CO_2 emission target at time t. The first term of eqn.(4a) shows the cost for reducing CO_2 emission and the second term shows the carbon tax to be paid. Eqn.(4b) shows the constraint to meet that the amount of CO_2 emission must be less than or equal to the emission target T_t.

In the case that the revenue of the carbon tax is assigned to the general funds, only a part of the revenue can be used for the investment of the CO_2 reduction behavior or the purchase of the CO_2 emissions permit. But in the case that the revenue of the carbon tax is assigned to the earmarked funds, all of the revenue can be used for the investment of the CO_2 reduction behavior or the purchase of the CO_2 emissions permit. As shown in **Fig.3**, in the case that all revenue is assigned to the investment of the CO_2 reduction behavior, the CO_2 reduction rate is improved to the level, s_2, where, s_2 is the level that the area enclosed by S_1, S_2 and marginal cost curve is equal to the area enclosed by S_2, '1' and t_1. In Fig. 3 t_2 denotes the subsidy for marginal reduction of CO_2 emission. In this case, the private expense is the sum of the cost for CO_2 reduction and the carbon tax shown in Fig. 3. This expense is much less than that in Fig. 2. Quantitative comparison will be discussed later.

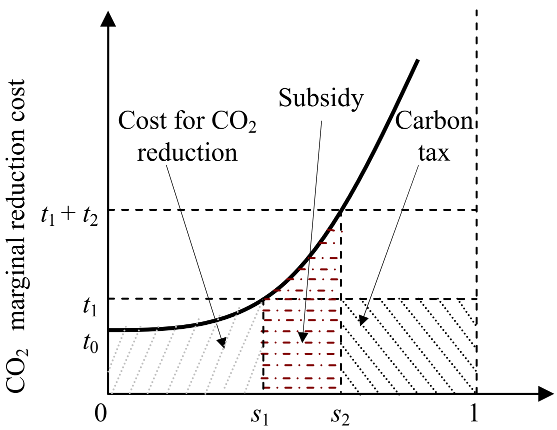


Fig.3. CO_2 reduction behavior, subsidy and carbon tax.

Kyoto Protocol regulates the reduction target on the sum of emissions between 2008 to 2012, hence, we evaluate the averaged value of these period. The data of the input-output matrix and price elasticity, etc, used in this paper are taken from Akazawa, et al. (2002).

3. THE PREDICTION FOR 2008 TO 2012

Looking at the transition of CO_2 emissions from 1990, it increased in U.S., Japan and France, almost 17%, 11% and 2%, respectively, in 2000. In Russia, it decreased 37% in 1996, because of the collapse of the Soviet Union, and the economic confusion after that. In Germany and U.K., it decreased 15% and 7%, respectively, in 2000 according to the data of UNFCCC (2003).

According to the prediction of the Energy Information Administration (2003) for the transition of CO_2 emissions from 1990 to 2010, it will increase 33.1%, 24.2% and 5.9% in U.S., Japan and France, respectively, and it will decrease 20.4%, 14.4% and 0.6% in Russia, Germany and U.K., respectively.

The prediction of the CO_2 emissions in 2010, which represent the averaged emissions between 2008 and 2012, is shown in **Table 2**. The values in the second and third columns show the percentage change from 1990. The values of France, U.K. and Germany show the reduction targets in EU bubbles. The values in the fourth columns show the Forest Absorption Credits admitted in Marrakesh accords, COP7. The values in the fifth column show the amount of surplus emissions of each country, taking into account of the prediction of CO_2 emissions and the forest absorptions.

Table 2. The prediction of the averaged emissions between 2008 to 2012

	Reduction Target	Prediction in 2010	Forest Absorption	Surplus Emission Permit
Japan	−6.0 %	+24.2 %	13.00	−79.1
U.S.	−7.0 %	+33.1 %	28.00	−519.1
U.K.	−12.5 %	−0.6 %	0.37	−18.6
France	−0.0 %	+5.9 %	0.88	−5.4
Germany	−21.0 %	−14.4 %	1.24	−17.0
Russia	−0.0 %	−20.4 %	33.00	+164.8

(10^6 ton carbon)

4. DATA USED FOR ANALYSIS

Input-output coefficients are obtained from Japan, US, EU and ASEAN International Input-Output Table (1990). It is assumed that carbon tax is imposed on the consumption of coals, natural gas and oil products. It is assumed that CO_2 emissions coefficients in Japan, that is, the amount of CO_2 emissions per unit production in each sector is estimated from the basic unit of CO_2 emissions based on Basic Unit of CO_2 emissions Based on the Input-Output Table (1997). CO_2 emissions coefficients in other countries are estimated from Japanese emissions coefficients and the amount of consumption of coals, natural gas and oil products in each country. **Table 3** shows CO_2 emissions coefficients in each country for each sector.

Table 3. CO_2 emissions coefficients

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

(ton carbon/unit production)

5. SCENARIO SETTING

As shown in Table 2, Japan, U.S. and EU countries must take additional policies to achieve the reduction targets of the Kyoto Protocol. We will consider carbon tax and emissions trading as the national policy. To evaluate the influence on the revenue, the price of emissions trading, and the amount of carbon dioxide emissions, etc., we postulate three scenarios as follows:

< **Scenario I** >
Each country reduces its emissions by the carbon tax, without the emissions trading.
< **Scenario II** >
Each country reduces its emissions by the carbon tax and the emissions trading among Japan, EU and Russia.
< **Scenario III** >
Each country reduces its emissions by the carbon tax and the emissions trading among Japan, EU, Russia and U.S.

In these Scenarios, the reduction target of U.S. is assumed to be 18% reduction of emissions per unit GDP, during 2002 and 2012 in Scenarios I and II, and the value of Kyoto protocol in Scenario III.

6. POLICY ASSESSMENT

We will compare two cases that the revenue of the carbon tax is assigned to the general funds and to the earmarked funds. For comparison, the ratio of investment to the CO_2 reduction behavior is assumed to be zero in the general funds case.

Table 4. The necessary carbon tax rate

(a) General funds case

	Japan	U.S.	U.K.	France	Germany
Scenario I	236.9	80.6	145.9	224.7	180.8
Scenario II	131.3	80.6	131.3	131.3	131.3
Scenario III	115.2	115.2	115.2	115.2	115.2

($/ton carbon)

(b) Earmarked funds case

	Japan	U.S.	U.K.	France	Germany
Scenario I	58.1	4.2	18.4	10.9	13.5
Scenario II	15.7	4.2	15.7	10.9	13.5
Scenario III	23.7	23.7	18.4	10.9	13.5

($/ton carbon)

Table 4 shows the necessary carbon tax to achieve the emissions reduction target of each country for each scenario. We can find that the carbon tax is reduced to one fourth or fifth in the earmarked funds case compared with the general funds case. We also find that the more the range of emissions trading expands, the more the carbon tax is getting lower.

For the general funds case in Table 4 (a), if we use only carbon tax to reduce CO_2 emissions, that is, in Scenario I carbon tax rate would become more than 200 dollars/ton carbon in Japan. This is because the energy technology for saving energy has been improved drastically in the Japanese industries since the time of oil crisis. The reason why the carbon tax rate in France in Scenario I is high, is that nuclear power plants are widely used for electric power generation. If we use emissions trading in addition to the carbon tax, carbon tax rate is reduced to somewhere around 100 dollars/ton carbon as shown in Scenario II in Table 4 (a). If we expand the number of countries to join the emissions trading, the carbon tax rate could be further reduced.

For the earmarked funds case in Table 4 (b), carbon tax rate in Scenario III is higher than in Scenario II, except in France and in Germany. The reason for this result is that since the amount of CO_2 emissions in U.S. is huge, price for the emissions trading would be raised in Scenario III. The reason why the carbon tax rate in each scenario is identical in France and in Germany, is that carbon tax rate is lower than the price for the emissions trading in both countries.

If we compare the earmarked funds case with the general funds case in Japan, the necessary carbon tax rate is reduced to one fourth to one fifth. This shows that the subsidy for reducing CO_2 emissions is quite effective.

Fig. 4 shows the transition of CO_2 emissions in each scenario both for the general funds case and the earmarked funds case. "Prediction as it is" shows the case that the carbon tax and/or emissions trading are not introduced. The target level of CO_2 emissions is achieved only in Scenario I. Only a few CO_2 emissions are reduced in Scenarios I and II. This implies that the price for the emissions trading is cheaper than the cost of reducing CO_2 emissions based on the carbon tax.

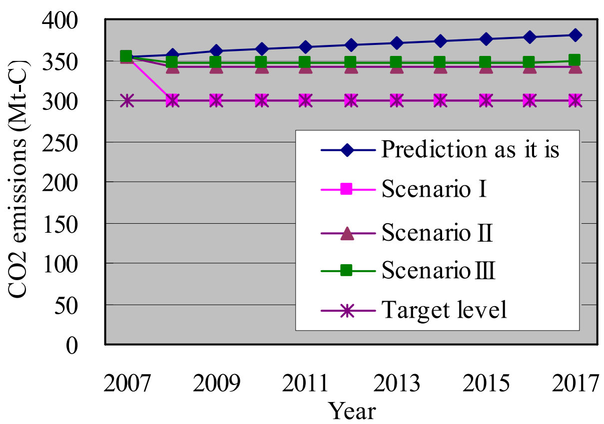
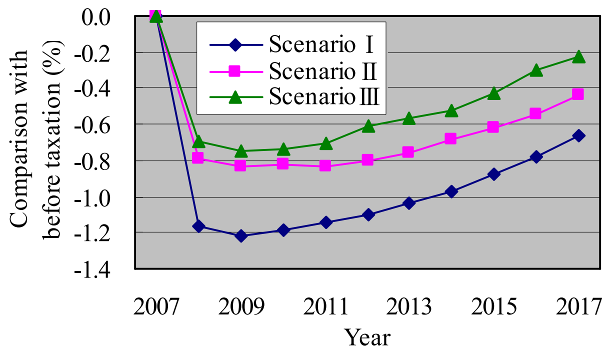
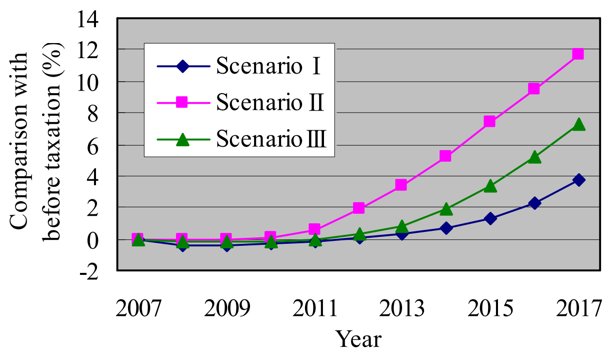


Fig. 4. Transition of CO_2 emissions in each scenario

Fig. 5 shows the transition of production output in each scenario for the general funds case and for the earmarked funds case. For the general funds case the production output is decreased about 1% in each scenario right after the taxation. Even after 10 years the level of the production output does not recover up to the level before the taxation. For the earmarked funds case production output is not affected so much by the taxation. Especially in Scenario II production output level grows after three years of taxation.



(a) General funds case

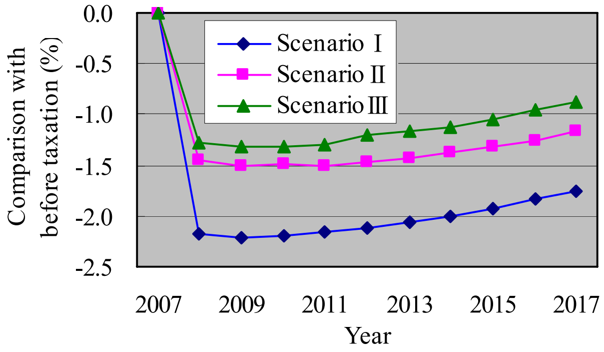


(b) Earmarked funds case

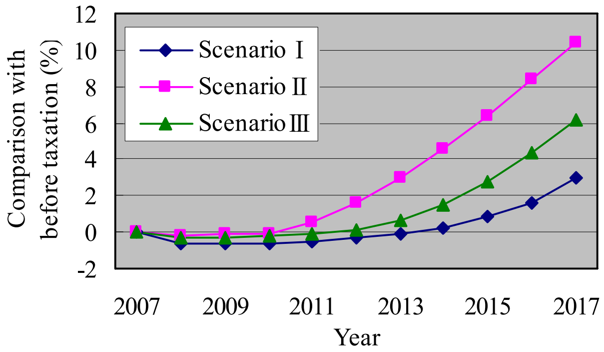
Fig. 5. Transition of production output in each scenario

Fig. 6 shows the transition of the profit in each scenario for the general funds case and for the earmarked funds case. For the general funds case the profit is decreased about 1.5 to 2% depending on the scenario right after the taxation. Even after 10 years the level of the profit does not recover up to the level before the taxation. For the earmarked funds case profit is not affected so much by the taxation just like in the case of production output.

Fig. 7 shows the transition of the economic growth rate in each scenario for the general funds case and for the earmarked funds case. For the general funds case the economic growth rate is about -0.6 to -1% depending on the scenario right after the taxation. In Japan we have never experienced minus growth rate for more than four years. Therefore, bad influence of carbon tax to the economy is inevitable for the general funds case. For the earmarked funds case the economy is not affected by the carbon tax except the period of right after the taxation.

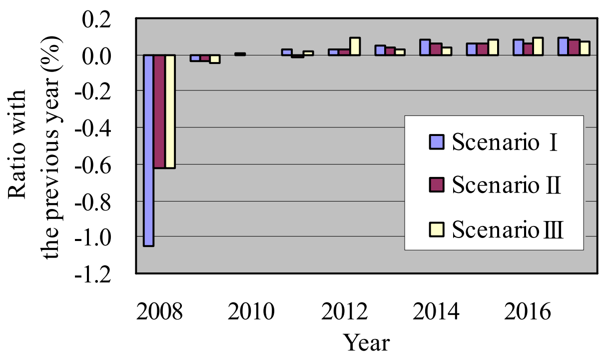


(a) General funds case

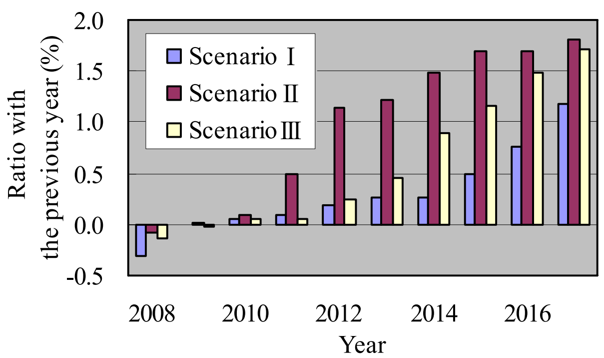


(b) Earmarked funds case

Fig. 6. Transition of profit in each scenario



(a) General funds case



(b) Earmarked funds case

Fig. 7. Transition of economic growth rate in each scenario

7. CONCLUDING REMARKS

Since Japanese industries have already improved the efficiency of consuming energy extensively, it is not rational to achieve the emissions reduction target with the carbon tax only. Joining the emissions trading, the undesirable influence on the profit would be reduced to half, and it would become more profitable by increasing the number of trading countries. Considering the application of the carbon tax, negative influence on the economy would be avoided by taking the earmarked funds policy.

The influence of the carbon tax is concentrated on the particular sectors, such as steel and chemistry industries (Sectors 3 and 4). We need some special considerations to such heavily energy consuming sectors to avoid a big influence of carbon tax.

We need further analysis for the second commitment period including Non-Annex 1 countries for CO_2 emissions cooperating with Annex 1 countries (Rose, et al., 1998).

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