Emission Trading, Joint Implementation, and Minimum Abatement Cost*

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This study tries to find the impacts of emission trading and joint implementation policies on the total CO_2 abatement cost. Both policies were proposed in 1997 Kyoto Protocol. Some studies concluded that the emission trading was the most cost-effective policy. It is also believed that the joint implementation can reduce the abatement costs when the investing country's abatement cost is higher than it in the host country. And the joint implementation will strip the opportunity of doing the domestic abatement action by the host country. Whenever the joint implementation can be applied, the benefits obtained by the investing country must be higher than the lost of opportunity cost in the host country. This study finds that the emission trading and joint implementation can be applied simultaneously when the abatement technology used in each country has significant difference. Meanwhile, the total abatement costs of the whole system, that is the summation of individual country's abatement cost, will be minimal to achieve the CO_2 abating target.

Keywords: *Joint Implementation, Emission Trading, Minimal Abatement Cost*

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I. Introduction

Two economic instruments, emission trading and joint implementation, for reducing CO_2 emission were brought out in 1997 Kyoto Protocol. Essentially, emission trading is similar to tradable emission permits that are already applied to control the emission of SO_2 in America. The policy of emission trading can be operated by several approaches with the same character that the rights of emission can be tradable in order to maintain fixed amount of CO_2 emission with the minimal abatement cost. Joint Implementation(JI) is a new approach of emission trading[1].

In general, there are three kinds of cost savings generated from emission trading: emission trading between firms, emission averaging among sources within a firm, and emission trading through time (Cropper and Oates, 1992). Theoretically, Baumol and Oates (1971) and Montgomery (1972) proved that the minimal abatement cost could be obtained under the policy of emission trading. There were also some different studies did many empirical estimates of cost savings from the emission trading through firms and emission averaging among sources (Arkinson and Lewis, 1974; Seskin, Anderson, and Reid, 1983; Moloney and Yandle, 1984; McGartland & Oates, 1985; Tietenberg, 1985, Rubin, 1996). All of their researches concluded that emission trading could make potentially large savings. It is no doubt that emission trading is an efficient strategy for controlling CO_2 pollution.

Joint implementation is an approach for reducing the global abatement cost to achieve the particular target of greenhouse gases abatement through international cooperation. The Kyoto Protocol has incorporated variety of provisions for cooperative implementation mechanisms. The Article 6 has authorized the transferring or acquisition of “emission reduction units (ERUs)” from joint implementation projects among Annex I parties. But Article 12 has established the “Clean development mechanism” (CDM) to transfer or acquire the “certified emission reductions (CERs)” among Annex B[2] members (Zhang, 1997). So, the basic incentive of JI is that the investing country could fulfill her CO_2 reduction target by investing the abatement projects in the host country. Because the cost of CO_2 reduction for investing country is usually higher than that is for the host country. Thus, the investment can lower the total cost of CO_2 reduction in order to reach the commitment under the joint implementation project. Eventually, the investing country can obtain the credits of CO_2 emission accounts from the host country (Hagem, 1996; Zhang, 1997; 1998).

When the host country accepts a new technology or equipment of CO_2 abatement from the investing country, the investing country will obtain the ERUs from the host country. Thus, the opportunity cost of CO_2 abatement in the host country will increase. It is necessary to know what conditions are for the host country when she decides to attend the joint implementation projects or not.

Since the countries attended in the projects of emission trading or joint implementation are restricted to be Annex I countries. It is believed that the Annex I country will not join one project only during a fixed period. Each Annex I country should prefer to join two different projects simultaneously in order to have better achievement for reducing CO_2 emission. Thus, this study tries to discuss and to derive the minimal global abatement costs under the emission trading and joint implementation projects applied simultaneously. Emission trading and JI projects are treated as two different approaches for achieving a certain global CO_2 abatement target.

II. Basic Model

Montgomery (1972) employed the optimal control theory to prove that the abatement cost of each firm and whole market could fulfill cost efficiency if the market of emission trading was perfect competition. This study tries to apply the Montgomery's idea (1972) to set up the theoretical model to employ the emission trading and joint implementation policies simultaneously. Two countries (i and j) are involved in the policy of emission trading or joint implementation project. Country i is defined as the host country with poor CO_2 abatement technology, and country j is the investing country with advanced abatement technology. The emission trading market or joint implementation market is assumed to be perfect competition. The definitions of variables are as follows:

- a_i, a_j : The amount of CO_2 abatement for each country.
- $\overline{a_i}, \overline{a_j}$: The promised amount of CO_2 reduction during a period of time for two countries.
- y_i, y_j : The net demand of CO_2 emission trading for each country. If it is positive, then the country will be the buyer in the emission trading market. While it will be the seller of emission permits if the net demand is negative.
- k_j : The amount of CO_2 abatement in country i under the joint implementation.
- $C_i(a_i, k_j)$: The abatement cost function of country i that is the function of a_i and k_j. And $\frac{\partial^2 C_i}{\partial k_j^2} > 0$, $\frac{\partial C_i}{\partial a_i} > 0$, $\frac{\partial^2 C_i}{\partial a_i^2} > 0$ must be true. But the signs of $\frac{\partial C_i}{\partial k_j}$ and $\frac{\partial^2 C_i}{\partial a_i \partial k_j}$ can not be defined. If the host country i is the beneficiary of technological diffusion effects of joint implementation project, then their signs

should be negative, otherwise, they would be positive.

- $C_j(a_j)$: The abatement cost function of country j that is the function of a_j. And $\frac{\partial C_j}{\partial a_j} > 0$, $\frac{\partial^2 C_j}{\partial a_j^2} > 0$ must be true.
- $J(k_j)$: The cost function of attending joint implementation project for country j, and $\frac{\partial J}{\partial k_j} > 0$, $\frac{\partial^2 J}{\partial k_j^2} > 0$.
- P_{ET}: The unit price of CO_2 trade between two countries under the emission trading.
- P_{JI}: The unit payment of CO_2 abatement under joint implementation. If it is positive, it means that the investing country has to buy the ERUs from the host country under JI. But, if it is negative, this study assumes that the investing country has feedback from host country.

All cost functions are convex function. Besides, the ERUs for country j under joint implementation will be aggregated in the investing country's Green House Gas account.

This study assumes that the objective function of country j is to minimize CO_2 abatement costs with emission trading and joint implementation policies applied simultaneously. The objective function is:

$$\text{Min} \quad C_j(a_j) + J(k_j) + P_{ET} \cdot y_j + P_{JI} \cdot k_j \tag{1}$$

$$\text{s.t.} \quad y_j + a_j + k_j = \bar{a}_j, \tag{2}$$

$$a_j, k_j \geq 0 \tag{3}$$

Equation (1) shows that the investing country can apply emission trading and joint implementation policies together to reach the target of CO_2 reduction. $P_{JI}\,k_j$ is transfer expenditure. In general, this term is a lump sum of investment.

Equation (2) shows the obligation of the investing country to achieve a specific abatement target.

By applying the Lagrange method, the first-order conditions of the model are:

$$\tilde{L} = C_j(a_j) + J(k_j) + P_{ET} \cdot y_j + P_{JI} \cdot k_j + \lambda \cdot (y_j + a_j + k_j - \bar{a}_j) \tag{4}$$

$$\frac{\partial \tilde{L}}{\partial y_j} = P_{ET} + \lambda = 0\,, \tag{5}$$

$$\frac{\partial \tilde{L}}{\partial a_j} = \frac{\partial C_j}{\partial a_j} + \lambda = 0\,, \tag{6}$$

$$\frac{\partial \tilde{L}}{\partial k_j} = \frac{\partial J}{\partial k_j} + P_{JI} + \lambda = 0\,, \tag{7}$$

$$\frac{\partial \tilde{L}}{\partial \lambda} = y_j + a_j + k_j - \bar{a}_j = 0\,, \tag{8}$$

$$\lambda \le 0,\quad a_j, k_j \ge 0\,,\quad y_j \in R \tag{9}$$

While country i also tries to minimize the CO_2 abatement costs listed in equation (10).

$$\text{Min}\quad C_i(a_i, k_j) + P_{ET} \cdot y_i - P_{JI} \cdot k_j \tag{10}$$

$$\text{s.t.}\quad y_i + a_i = \bar{a}_i\,, \tag{11}$$

$$a_i, k_j \ge 0 \tag{12}$$

By applying the Lagrange method, the first-order conditions of the model are:

$$\tilde{L} = C_i(a_i, k_j) + P_{ET} \cdot y_i - P_{JI} \cdot k_j + \mu \cdot (y_i + a_i - \bar{a}_i) \tag{13}$$

$$\frac{\partial \tilde{L}}{\partial y_i} = P_{ET} + \mu = 0\,, \tag{14}$$

$$\frac{\partial \tilde{L}}{\partial a_i} = \frac{\partial C_i}{\partial a_i} + \mu = 0\,, \tag{15}$$

$$\frac{\partial \tilde{L}}{\partial k_j} = \frac{\partial C_i}{\partial k_j} - P_{JI} = 0, \tag{16}$$

$$\frac{\partial \tilde{L}}{\partial \mu} = y_i + a_i - \bar{a}_i = 0, \tag{17}$$

$$\mu \leq 0, \quad a_i, k_j \geq 0, \quad y_i \in R \tag{18}$$

In equation (16), if P_{JI} is positive, it means that the investing country has to pay for ERUs even the investing country provides the new abatement technology to the host country. But the host country has no beneficiary of technological diffusion effects from the new technology. So, the abatement cost of host country will rise when k_j is increased ($\frac{\partial C_i}{\partial k_j} > 0$). When P_{JI} is negative, the sign of $\frac{\partial C_i}{\partial k_j}$ is negative. It means that the host country is willing to pay the feedback to the investing country, since the host country has the beneficiary of technological diffusion effects from the new technology. Therefore, the term of $(-P_{JI} \cdot k_j)$ becomes the opportunity cost of the host country. And, the investing country even can get ERUs with the payment from the host country.

If second-order conditions for two models are satisfied, then the equilibrium solutions of emission trading and joint implementation, that both are the function of (a_i^*, a_j^*, k_j^*, y_i^*, y_j^*), can be derived. In the meantime, the minimal abatement cost for each country is also fulfilled.

III. Theoretical Analysis

Based on the information obtained from the first-order conditions of each individual country's model, the marginal costs function of CO_2 abatement for each country will be listed as follows:

$$\frac{\partial C_i(a_i^*, k_j^*)}{\partial a_i} = \frac{\partial C_j(a_j^*)}{\partial a_j} = \frac{\partial J(k_j^*)}{\partial k_j} + \frac{\partial C_i(a_i^*, k_j^*)}{\partial k_j} = P_{ET}^*, \tag{19}$$

$$\frac{\partial C_i(a_i^*, k_j^*)}{\partial k_j} = P_{JI}^*, \tag{20}$$

Equation (19) shows that both of the emission trading and joint implementation projects can be applied simultaneously in each country. It also concludes that the marginal abatement cost of each individual country equal to the price of CO_2 tradable emission permits between two countries under emission trading. It concludes that the joint implementation projects only can be adopted between two countries when the increment of opportunity cost of the host country caused by the investment from the investing country j must be less than the marginal cost of doing the domestic CO_2 abatement action in the host country ($\frac{\partial C_i\left(a_i^*, k_j^*\right)}{\partial a_i} > \frac{\partial C_i\left(a_i^*, k_j^*\right)}{\partial k_j}$). These results are just same as the conclusion obtained from the studies of Baumol and Oates (1971) and Montgomery (1972). Equation (20) shows that the unit payment of ERUs under joint implementation projects must equal to the opportunity cost generated from the host country, because the investment of joint implementation by investing country will take over the opportunity of doing the domestic CO_2 abatement action in host country.

Hagem (1996) and Zhang (1997; 1998) believed that the joint implementation projects would be successful if the investing country’s abatement cost was higher than that in the host country. However, it is believed that the investing country’s investment action under joint implementation project will strip the opportunity of host country’s domestic action for CO_2 emission abatement. In the meantime, the joint implementation project also generates the diffusion effects of abatement technology in the host country (Kuik, Peters, and Schrijver, 1994). Therefore, the investing country's abatement technology must be much more advanced than that in the host country in order to avoid the higher opportunity cost of host country's domestic action caused by joint implementation.

If the objective function is modified to minimize the summation abatement costs for two countries, the new objective function and constraints are as follows:

$$Min\ C_i(a_i, k_j) + C_j(a_j) + J(k_j) \tag{21}$$

$$s.t.\ \ a_i + a_j + k_j = \overline{a} \tag{22}$$

$$a_i, a_j, k_j \geq 0 \tag{23}$$

$$\overline{a}_i + \overline{a}_j = \overline{a} \tag{24}$$

This model assumes that each country will not distort its own CO_2 abatement goal, thus, the total amount of CO_2 reduction promised ($\overline{a}$) for two countries must be equal to the summation of each country's promised ($\overline{a}_i, \overline{a}_j$). By applying the Lagrange Equation, the first-order conditions of the model also can be derived as follows:

$$\tilde{L} = C_i(a_i, k_j) + C_j(a_j) + J(k_j) - \varphi \cdot (a_i + a_j + k_j - \overline{a})$$

$$\frac{\partial \tilde{L}}{\partial a_i} = \frac{\partial C_i}{\partial a_i} - \varphi = 0 \tag{25}$$

$$\frac{\partial \tilde{L}}{\partial a_j} = \frac{\partial C_j}{\partial a_j} - \varphi = 0 \tag{26}$$

$$\frac{\partial \tilde{L}}{\partial k_j} = \frac{\partial C_i}{\partial k_j} + \frac{\partial J}{\partial k_j} - \varphi = 0 \tag{27}$$

$$\frac{\partial \tilde{L}}{\partial \varphi} = (a_i + a_j + k_j - \bar{a}) = 0 \tag{28}$$

$$\varphi \leq 0, \quad a_i, a_j, k_j \geq 0 \tag{29}$$

The joint-cost equilibrium solutions of this model, (a_i^{**}, a_j^{**}, k_j^{**}, φ^{**}), can be obtained if the second-order conditions are fulfilled. From the equations (25), (26), and (27), this study can derive the relationship between two countries' abatement costs as follows:

$$\frac{\partial C_i\left(a_i^{**}, k_j^{**}\right)}{\partial a_i} = \frac{\partial C_j(a_j^{**})}{\partial a_j} = \frac{\partial J\left(k_j^{**}\right)}{\partial k_j} + \frac{\partial C_i\left(a_i^{**}, k_j^{**}\right)}{\partial k_j} = \varphi \tag{30}$$

This equation shows that the marginal abatement costs between two countries must be equal. The same conclusion was also found in the analysis of tradable emission permit (Baumol and Oates, 1971; Montgomery, 1972). But the major concern of this study is to apply the mechanism of joint implementation and emission trading projects simultaneously. The total abatement cost is the summation of the investment costs for the investing country j ($\frac{\partial J}{\partial k_j}$) and opportunity abatement costs for the host country i ($\frac{\partial C_i}{\partial k_j}$) Besides, the increment of opportunity costs of host country i under joint implementation project must be less than the marginal abatement costs of doing domestic abatement actions ($\frac{\partial C_i}{\partial k_j} < \frac{\partial C_i}{\partial a_i}$).

IV. Efficiency Analysis of Total Abatement Costs

This study assumes that the total abatement cost is equal to the summation of two countries' abatement costs. By applying the emission trading and joint implementation projects simultaneously, the constraint of the amount of CO_2 abatement with the equilibrium solution in joint-cost model can be listed in equation (31).

$$a_i^{**} + a_j^{**} + k_j^{**} = \bar{a}_j + \bar{a}_i = \bar{a} \tag{31}$$

Because y_i^{**} and y_j^{**} are equal amount with different sign when the equilibrium solution is solved, so the values of y_i^{**} and y_j^{**} are not significant in the model (Montgomery, 1972; Rubin, 1996). Compared with the constraints of the individual country's model, $a_i^* + y_i^* = \bar{a}_i$, $a_j^* + y_j^* + k_j^* = \bar{a}_j$, it concludes that $a_i^* = a_i^{**}$, $a_j^* = a_j^{**}$ and $k_j^* = k_j^{**}$ must be true.

The optimal solution of the model with the emission trading and joint implementation policies, (a_i^*, a_j^*, k_j^*, y_i^*, y_j^*), can be derived above. Suppose the other solution ($\tilde{a}_i$, $\tilde{a}_j$, $\tilde{k}_j$, $\tilde{y}_i$, $\tilde{y}_j$) of the model, that is feasible and generates a lower total abatement cost, is also existed. Thus, the solution of ($\tilde{a}_i$, $\tilde{a}_j$, $\tilde{k}_j$, $\tilde{y}_i$, $\tilde{y}_j$)can satisfy the following equations:

$$C_i(a_i^*, k_j^*) + C_j(a_j^*) + J(k_j^*) > C_i(\tilde{a}_i, \tilde{k}_j) + C_j(\tilde{a}_j) + J(\tilde{k}_j) \tag{32}$$

$$\tilde{a}_i + \tilde{a}_j + \tilde{k}_j + \tilde{y}_j + \tilde{y}_i \geq \bar{a} \tag{33}$$

When the market of emission trading reaches the equilibrium point, the total abatement cost could be rewritten as follows:

$$\begin{aligned} &C_i(a_i^*, k_j^*) + P_{ET}^* \cdot y_i^* + P_{JI}^* \cdot k_j^* + C_j(a_j^*) + J(k_j^*) + P_{ET}^* \cdot y_j^* - P_{JI}^* \cdot k_j^* > \\ &C_i(\tilde{a}_i, \tilde{k}_j) + \tilde{P}_{ET} \cdot \tilde{y}_i + \tilde{P}_{JI} \cdot \tilde{k}_j + C_j(\tilde{a}_j) + J(\tilde{k}_j) + \tilde{P}_{ET} \cdot \tilde{y}_j - \tilde{P}_{JI} \cdot \tilde{k}_j \end{aligned} \tag{34}$$

However, (a_i^*, a_j^*, k_j^*, y_i^*, y_j^*) was already proved to be the optimal solution with minimal abatement cost, so, at least, the abatement cost of one country, host country or investing country, must be higher than the cost of the

$(\tilde{a}_i,\ \tilde{a}_j,\ \tilde{k}_j,\ \tilde{y}_i,\ \tilde{y}_j)$ solution as follows:

$$C_i(a_i^*, k_j^*) + P_{ET}^* \cdot y_i^* + P_{JI}^* \cdot k_j^* > C_i(\tilde{a}_i, \tilde{k}_j) + \tilde{P}_{ET} \cdot \tilde{y}_i + \tilde{P}_{JI} \cdot \tilde{k}_j \tag{35}$$

or

$$C_j(a_j^*) + J(k_j^*) + P_{ET}^* \cdot y_j^* - P_{JI}^* \cdot k_j^* > C_j(\tilde{a}_j) + J(\tilde{k}_j) + \tilde{P}_{ET} \cdot \tilde{y}_j - \tilde{P}_{JI} \cdot \tilde{k}_j \tag{36}$$

Obviously, this conclusion is self-contradictory with the formal analysis. Therefore, $(\tilde{a}_i,\ \tilde{a}_j,\ \tilde{k}_j,\ \tilde{y}_i,\ \tilde{y}_j)$ is not the feasible equilibrium solution that is better than the original solution, $(a_i^*,\ a_j^*,\ k_j^*,\ y_i^*,\ y_j^*)$, of the model. This proves that the market equilibrium will minimize the individual country's abatement cost and the summation of total abatement costs for two countries simultaneously.

Montgomery (1972) and Rubin (1996) concluded that the total abatement costs of firms, the summation of individual firm's minimal abatement cost, would be minimum under the policy of emission trading. However, their studies did not concern the difference of technology level for reducing CO_2 emission between two firms. After combining the joint implementation project and emission trading in the model, this study obtains the same conclusion. But it is better now since the model has already concerned the difference of abatement technology between two countries.

Since the joint-cost function is convex, the joint-cost model should have only one global minimum solution. Thus, whenever the difference of level for abatement technological progress between two countries is the major concern, the summation of abatement costs for two countries is not minimal under only one policy, the emission trading or joint implementation.

V. Conclusion

Hagem (1996) and Zhang (1997; 1998) argued that the joint implementation was not available for every situation. They believed that this policy would be useful if two countries had different CO_2 abatement technology to achieve the same target of CO_2 reduction. It is believed that the investing country with the advanced abatement technology could obtain ERUs after transferring the new abatement technology to host country. However, the host country also could reduce CO_2 emission more efficiently and less costly with the advanced abatement technology. For achieving the whole world target of CO_2 reduction, the ERUs generated in the host country would be transferred to the investing country. So, the joint implementation policy could help the investing country to reduce CO_2 emission with the lowest cost. But both of their studies neglected that the investing country had already stripped the opportunity of doing the domestic abating emission action and the effect of the diffusion effects of abatement technology in the host country. The host country must concern these opportunity costs in order to compensate or to be compensated for the total benefit of joint implementation policy.

If the joint implementation project can be applied efficiently, the marginal abatement cost of the investing country must be higher than that in the host country. In the meantime, the increment of marginal opportunity cost in host country caused by investing country must be lower than the marginal abatement cost for reducing one unit of CO_2 emission in the host country.

Both emission trading and joint implementation policies are agreed by most economists to be the effective instruments for reducing the global CO_2 abatement cost. This study concludes that two policies are different technically rather than essentially. Emission trading is a trade of emission rights with the basic presumption of that, at least, one country has surplus of CO_2 emission. Then, this country can sell the surplus. It is not necessary to concern the abatement technology used in each country. But the joint implementation project is a kind of investment. The reason why the host country would like to accept the advanced abatement technology from the investing country is that the host country can reduce CO_2 emission more efficiently. This policy must concern the difference of abatement technology between two countries. Because the use of advanced abatement technology will strip the opportunity of domestic abatement action in the host country. The advantages of applying new technology have to compensate this lost for host country. But if the abatement technological diffusion effects were significant, then the host country would like to pay the fee in order to provide the incentive for investing country.

This study also concludes that the summation of each individual country's minimal abatement cost under joint implementation and emission trading projects applying together will equal to the minimal system abatement cost. Bamoul and Oates (1971), Montgomery (1972), and Rubin (1996) also had the same conclusion in their studies. This conclusion implies that any restriction of emission trading and joint implementation policies will downgrade the efficiency of abatement action.

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Notes

1. Emission trading is originally designed to buy and sell the initial endowment of emission permits between Annex B countries. Joint implementation is designed for transferring or acquisition of "emission reduction units (ERUs)" between Annex I countries by applying the new abatement technology investment.
2. The countries in Annex I are promised to reduce CO_2 emission during a period of time. But the countries in Annex B include the countries that are promised or not promised to reduce CO_2 emission during a period of time.

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排放權交易、跨國聯合減量與減量成本極小化*

魏 國 棟**

本研究係探討排放權交易機制與跨國聯合減量機制對二氧化碳減量成本的影響，因為這兩種機制均是 1997 年京都議定書中所建議的二氧化碳減量政策。一些研究文獻已指出排放權交易機制是最具成本有效性的政策；同時，只要投資國的二氧化碳減量成本高於被投資國，透過跨國聯合減量政策的執行，減量成本一定會減少。當然，跨國聯合減量政策的執行，一定會排除被投資國原有的減量措施，而以投資國之先進減量技術取代之。一但執行跨國聯合減量政策，投資國的利得理應高於被投資國損失的機會成本。所以本研究發現在兩國減量技術水準有顯著差異時，若能同時執行排放權交易政策與跨國聯合減量政策，則在達成承諾減量的目標下，兩國二氧化碳減量成本之加總將會達於極小化。

關鍵詞：跨國聯合減量、排放權交易、減量成本極小

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