RIETI Discussion Paper Series 11-E-043

Free-Riding-Proof International Environmental Agreements

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http://www.rieti.go.jp/en/

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April 2011

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Abstract

We study international free-riding-proof coalitions to solve trans-boundary environmental problems such as global warming. We show that the free-riding problem is rather serious so that a free-riding-proof coalition can consist of only a small number of countries. In the optimal coalitional structure, therefore, the world would be divided into many small groups. For each group, if countries are symmetric, their individual incentives to join a group are identical across the two regimes of environmental coalitions: the non-transferable utility (NTU) regime and transferable utility (TU) regime. If member countries are asymmetric, however, groups are more stable under the TU regime than under the NTU regime since the former regime enables the member countries to pool their incentives. International cooperation (within each group) on carbon taxes is shown to be equivalent to the NTU regime, while emission permit trading is shown to be equivalent to the TU regime. Therefore, the emission permit trading system can be considered to be superior in the world of asymmetric countries.

Keywords: global warming, stable coalition, carbon taxes, and emission permit trading.

JEL classification: C71; C72; D71; F53; H23; Q54

* We are grateful to Yoko Sakamoto for her helpful discussion and to seminar participants at RIETI for their useful comments. Part of this research was conducted when Taiji Furusawa visited the Weatherhead Center for International Affairs, Harvard University. He is grateful to Harvard University for its hospitality and to the Abe Fellowship for financial support.

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1 Introduction

As problems of global warming and ozone layer depletion are notable examples, some of recent environmental problems are truly global. International cooperation among sovereign nations is needed to achieve meaningful outcomes in mitigating the problem. There are indeed many international environmental agreements such as the Kyoto Protocol to tackle the global warming and the Montreal Protocol to prevent the ozone layer depletion. There are also other regional agreements; the European Union for example has launched a greenhouse gas trading scheme (Hahn 2008)

The free-rider problem, of course, is one of the leading obstacles of international cooperation. The United States and China, for example, did not join the Kyoto Protocol. Due to the positive externality arising from abatement efforts, there naturally exist free riding incentives. On one hand, a large environmental coalition is preferred in an attempt to lessen the environmental problem. But on the other hand, a large coalition is hard to sustain. An effective environmental coalition should be large enough to be effective to mitigate the problem, but small enough to be free-riding proof.

The equilibrium size of the international environmental coalition has been an issue of the literature. Barrett (1994) examines the case of symmetric countries and finds that only a small number of countries sign an international environmental agreement in many cases. He also shows that the contribution of the coalition to the environment is rather small if the equilibrium coalition is large. Barrett (2001) examines the same issue in the case of asymmetric countries with respect to the preferences for the environment, and shows that allowing monetary transfers among member countries increases the size of the coalition and greatly improves the welfare of the countries.[1]

We construct a more general model in which the size of the countries (and hence the collective preferences for the environment) and the abatement technology are different across the countries. We derive free-riding-proof stable coalition such that no member country has

[1]Carraro and Siniscalco (1993) and McEvoy and Stranlund (2009) among others also examine the size of environmental coalitions.

an incentive to leave the coalition to get free-riding benefits. We are particularly interested in the size of stable coalitions. Within the framework of our model, we confirm the results obtained by Barrett (1994, 2001) that the size of stable coalitions is rather small and internal transfers are effective in expanding stable coalitions. But our model admits coexistence of multiple coalitions, so the world may be divided into many small environmental coalitions.

We also derive stable coalitions in both cases of non-transferable utility (NTU) and transferable utility (TU). We formally show the correspondences of these two cases with the two most famous international environmental policies: carbon taxes and emission permit trading. That is, we show that the NTU game is equivalent to the carbon taxation while the TU game is equivalent to the emission permit trading. By comparing the results obtained from the analyses of the NTU and TU games, we conclude that emission permit trading is superior in the reduction of greenhouse gases if and only if member countries are asymmetric and that small countries with an efficient abatement technology will be a seller of the permits.[2]

2 Model

There are n countries in the world, and the set of countries is denoted by $N = \{1, 2, \cdots, n\}$. Each country i is characterized by its population measure m_i and pollution abatement technology parameter θ_i. All individuals in each country i are symmetric, and they individually make abatement efforts, whose level is denoted by $\tilde{g}_i$. The abatement cost for an individual in country i is given by $\theta_i c(\tilde{g}_i)$, where c is an increasing, convex function. Unless we specifically mention otherwise, function c is assumed to take a simple form of $c(\tilde{g}_i) = \tilde{g}_i^2/2$ throughout the paper.

To obtain analytical results, we specify a rather simplified social welfare function. Letting g_i denote country i's total abatement level, i.e., $g_i = m_i\tilde{g}_i$, we assume that country i's social welfare is given by

$$u_i = m_i \left[\sum_{j \in N} g_j - \theta_i c\left(\frac{g_i}{m_i}\right) \right].$$

[2]Which of the two regimes is better for mitigating the environmental problem does not only depend on economic efficiency but also on political and other factors. Cooper (2007) and Nordhaus (2006) argue that price instruments such as carbon taxes are preferable to quantity instruments such as emission quotas.

We consider the situation in which countries form a coalition to abate pollution. Individual countries in a coalition S are assumed to choose their individual abatement levels to maximize the joint welfare of countries in S, rather than its own social welfare. That is, if $i \in S$, country i selects g_i so as to maximize $\sum_{j \in S} u_j$ rather than to maximize u_i. Monetary (utility) transfers may or may not be allowed among countries in S. As we show later, the non-transferable utility (NTU) regime corresponds to the abatement by environmental taxation (i.e., carbon taxes in an attempt to reduce green house gases), while the transferable utility (TU) regime corresponds to the abatement by emission permit trading. We allow the existence of multiple groups in the world, as long as those groups do not overlap. As a result, the world will be partitioned into environmental coalitions.

We require each coalition to be free-riding proof. That is, the coalition should be stable in the sense that no country in the group has an incentive to leave the group. We assume that the remaining member countries would continue to cooperate within themselves in their individual abatement even when a country leaves the group. Let $V(S; g_{-S})$ denote joint welfare of the group S when member countries cooperate in setting their abatement levels while the outside countries select the aggregate abatement level of $g_{-S} \equiv \sum_{j \notin S} g_j$. That is, $V(S; g_{-S})$ is given by

$$V(S; g_{-S}) = \max_{\{g_j\}_{j \in S}} \sum_{j \in S} m_j \left[\sum_{k \in S} g_k + g_{-S} - \theta_j c \left(\frac{g_j}{m_j} \right) \right]. \tag{1}$$

Let $\{g_j^S\}_{j \in S}$ denote the arguments that maximize the expression in (1), i.e., $\{g_j^S\}_{j \in S}$ represents the abatement levels of member countries of S. Then, country i's social welfare when it joins the group S equals

$$v_i(S; g_{-S}) = m_i \left[\sum_{j \in S} g_j^S + g_{-S} - \theta_i c \left(\frac{g_i^S}{m_i} \right) \right], \tag{2}$$

and we have $V(S; g_{-S}) = \sum_{j \in S} v_j(S; g_{-S})$. Country i's social welfare when it leaves the group, on the other hand, is given by

$$v_i(S \setminus \{i\}; g_i^{\{i\}}, g_{-S}) = m_i \left[\sum_{j \in S \setminus \{i\}} g_j^{S \setminus \{i\}} + g_i^{\{i\}} + g_{-S} - \theta_i c \left(\frac{g_i^{\{i\}}}{m_i} \right) \right].$$

Under the NTU regime (without transfer), coalition S is *free-riding-proof stable* if $v_i(S; g_{-S}) \geq v_i(S \setminus \{i\}; g_i^{\{i\}}, g_{-S})$ for every member $i \in S$. Under the TU regime (with transfer), on the other hand, coalition S is *free-riding-proof stable* if $V(S; g_{-S}) \geq \sum_{j \in S} v_j(S \setminus \{i\}; g_i^{\{i\}}, g_{-S})$; there exists a payoff allocation that induces all countries in S to remain in S if this inequality is satisfied. The free-riding-proof stability is equivalent to the internal stability, except that the former allow multiple coalitions to coexist.[3]

3 Environmental Coalition

This section examines the stability of coalition S. We seek the largest stable coalition and characterize such coalitions.

We seek the largest stable coalition because larger coalitions realize higher average welfare of member countries. Indeed, the joint welfare V is strictly superadditive, i.e., $V(S_1 \cup S_2; g_{-(S_1 \cup S_2)}) > V(S_1; g_{-S_1}) + V(S_2; g_{-S_2})$ for any S_1 and S_2 such that $S_1 \cap S_2 = \emptyset$, as we can see immediately from the definition of V. Individual abatement is too small in a small group because member countries do not take account of the effect on non-members when they choose their individual abatement levels. But if S is too large, on the other hand, free-riding incentives are large for member countries so that S cannot be stable, as we show later.

Now, let us find g_i^S and derive $v_i(S; g_{-S})$. The first-order condition for the maximization problem in (1) is given by

$$\theta_i c' \left(\frac{g_i}{m_i} \right) = m_S, \tag{3}$$

where $m_S \equiv \sum_{j \in S} m_j$. Since we have assumed $c(\tilde{g}_i) = \tilde{g}_i^2/2$, we obtain from (3) that

$$g_i^S = \frac{m_i m_S}{\theta_i}.$$

[3]See Furusawa and Konishi (2011) for free-riding-proofness. They introduce the free-riding-proof core as a solution concept in the framework of public goods provision. The free-riding-proof core is more demanding and more suitable for the public goods provision problems. But the core requirement does not allow us to apply this stronger solution concept to our current problem in which multiple environmental coalitions should be allowed.

In particular, if $S = \{i\}$, then $g_i^{\{i\}} = m_i^2/\theta_i$. We substitute the derived g_i^S into (2) to obtain

$$\begin{aligned} v_i(S; g_{-S}) &= m_i \left[\sum_{j \in S} \frac{m_j m_S}{\theta_j} + g_{-S} - \frac{\theta_i}{2} \left(\frac{m_S}{\theta_i} \right)^2 \right] \\ &= m_i m_S \left[\sum_{j \in S} \frac{m_j}{\theta_j} - \frac{m_S}{2\theta_i} \right] + m_i g_{-S}, \end{aligned}$$

and hence

$$V(S; g_{-S}) = \sum_{j \in S} v_j(S; g_{-S}) = \frac{m_S^2}{2} \sum_{j \in S} \frac{m_j}{\theta_j} + m_S g_{-S}.$$

Moreover, we have

$$\begin{aligned} v_i(S \setminus \{i\}; g_i^{\{i\}}, g_{-S}) &= m_i \left[\sum_{j \in S \setminus \{i\}} \frac{m_j m_{S \setminus \{i\}}}{\theta_j} + \frac{m_i^2}{\theta_i} + g_{-S} - \frac{\theta_i}{2} \left(\frac{m_i}{\theta_i} \right)^2 \right] \\ &= m_i \left[m_{S \setminus \{i\}} \sum_{j \in S \setminus \{i\}} \frac{m_j}{\theta_j} + \frac{m_i^2}{2\theta_i} \right] + m_i g_{-S}. \end{aligned} \tag{4}$$

Country i has an incentive to join S under the NTU regime, if and only if

$$v_i(S; g_{-S}) - v_i(S \setminus \{i\}; g_i^{\{i\}}, g_{-S}) = m_i \left[m_i \sum_{j \in S \setminus \{i\}} \frac{m_j}{\theta_j} - \frac{(m_S - m_i)^2}{2\theta_i} \right] \tag{5}$$

is nonnegative. The first term in the square brackets in (5) represents an increment of other members' abatement when country i joins S, while the second term represents an increment of country i's abatement cost when it joins S. The expression in (5) is likely to be positive if m_i is large and if θ_i is large. If m_i is large, the increment of other member countries' abatement levels is large. If θ_i is large, country i does not have to increase its abatement much because its abatement technology is poor, and hence the cost of joining S is small even though it does incur a large abatement cost due to its inefficient abatement technology.

But the fact that a large and inefficient country is likely to have an incentive to join an environmental coalition does not mean that a group of such countries can indeed form a free-riding-proof coalition. Consider a group of symmetric countries such that $m_i = m$ and $\theta_i = \theta$ for all i. Then (5) is reduced to

$$v_i(S; g_{-S}) - v_i(S \setminus \{i\}; g_i^{\{i\}}, g_{-S}) = \frac{m^3(s-1)(3-s)}{2\theta}, \tag{6}$$

where $s = |S|$ denote the cardinality of the set S. This condition shows that under the NTU regime, the maximum number of a group members is three regardless of m and θ; as long as countries are symmetric, even large and inefficient countries, which have more incentives to join a group in general, can only form a group of size three. Indeed, since

$$V(S; g_{-S}) - \sum_{j \in S} v_j(S \setminus \{j\}; g_j^{\{j\}}, g_{-S}) = \sum_{j \in S} \left[v_j(S; g_{-S}) - v_j(S \setminus \{j\}; g_j^{\{j\}}, g_{-S}) \right]$$

is nonnegative if and only if $v_j(S; g_{-S}) - v_j(S \setminus \{j\}; g_j^{\{j\}}, g_{-S})$ is nonnegative, the maximum size of a group is three also under the TU regime if the countries are symmetric. The sustainable coalition can only be of limited size, and the grand coalition is not possible in general; as S becomes large, positive externality of increasing abatement efforts by member countries (represented by the first term in the square bracket of (5)) increases in the linear order, while each member's abatement costs (represented by the second term) increases in the geometric order. We record this finding as the first proposition.

Proposition 1 *Environmental coalition can only be of limited size. In the case where the abatement cost function is quadratic, the maximum number of group members is three, if countries are symmetric.*

Next, we show that in general, asymmetry in countries' characteristics helps them form a coalition. As we have seen, whether or not monetary transfer among group members is allowed does not affect incentives to join the group if countries are symmetric. If countries are asymmetric, however, their incentives to join the group are pooled so that the group is more likely to be immune to a unilateral deviation. We see this incentive pooling effect through examples.

First, let us consider the case in which two countries, 1 and 2, form a coalition. If follows immediately from (5) that

$$v_1(\{1,2\}; g_{-\{1,2\}}) - v_1(\{2\}; g_1^{\{1\}}, g_{-\{1,2\}}) = m_1 m_2 \left(\frac{m_1}{\theta_1} - \frac{m_2}{2\theta_1} \right), \tag{7}$$

$$v_2(\{1,2\}; g_{-\{1,2\}}) - v_2(\{1\}; g_2^{\{2\}}, g_{-\{1,2\}}) = m_1 m_2 \left(\frac{m_2}{\theta_2} - \frac{m_1}{2\theta_2} \right). \tag{8}$$

Under the NTU regime, therefore, country 1 has an incentive to stay in S if and only if $m_1\theta_1 \geq m_2\theta_2/2$, while country 2 has an incentive to stay in S if and only if $m_2\theta_2 \geq m_1\theta_1/2$. As we expect from the previous result that either country is likely to stay in S if it is large or inefficient relative to the other country. As a result, these two countries can form a coalition if and only if they are similar. Or equivalently, they cannot form a free-riding-proof coalition if they are sufficiently asymmetric (or more specifically if either one of the above inequality is violated). The situation is quite different under the TU regime, however. If monetary transfer is possible between the two country, the coalition can be designed to be free-riding-proof (i.e., internal transfer can be designed properly) if and only if the sum of (7) and (8) is nonnegative. Indeed, we have

$$V(\{1,2\}; g_{-\{1,2\}}) - v_1(\{2\}; g_1^{\{1\}}, g_{-\{1,2\}}) - v_2(\{1\}; g_2^{\{2\}}, g_{-\{1,2\}}) = \frac{m_1 m_2}{2}\left(\frac{m_1}{\theta_2} + \frac{m_2}{\theta_1}\right) > 0, \quad (9)$$

so that there always exists a payoff allocation (or monetary transfer) such that both countries have incentives to form a coalition that is sustainable. This is true even though countries are significantly asymmetric.

We can show the property in the case where three countries, 1,2, and 3, form a coalition. Letting μ denote the common ratio of m_i/θ_i for the three countries, we have

$$\begin{aligned} & V(S; g_{-S}) - \sum_{j \in S} v_j(S \setminus \{j\}; g_j^{\{j\}}, g_{-S}) \\ = \ & \frac{\mu}{2}\left[(m_2 - m_3)^2 + (m_3 - m_1)^2 + (m_1 - m_2)^2\right], \end{aligned}$$

which is zero if countries are symmetric, but takes a positive value otherwise. Asymmetry helps countries to form a free-riding-proof environmental coalition.

Proposition 2 *If countries are symmetric, the possibility of internal monetary transfer does not affect their incentive to form a coalition. If countries are asymmetric, however, internal transfer enables them to pool their incentives so that it helps them form a free-riding-proof environmental coalition.*

Before we close this section, let us further discuss the issue of the coalition size. Proposition 1 shows that the maximum number of countries in a group is three when countries are symmetric. Obviously, this number is disappointingly small. The question is whether this number is universal or only specific in that example. To partially answer the question, we generalize the abatement cost function to

$$c(\tilde{g}_i) = \frac{1}{\alpha}\tilde{g}_i^{\alpha};\ \ \alpha > 1,$$

while maintaining symmetry across countries. Now, it follow from (3) that $g_i^S = m_i\,(m_S/\theta_i)^{\frac{1}{\alpha-1}}$, and the counterpart of (5) can be easily computed to be

$$v_i(S) - v_i(S\setminus\{i\}) = \frac{m^2}{\alpha}\left(\frac{m}{\theta}\right)^{\frac{1}{\alpha-1}}\left[(\alpha-1)\left(s^{\frac{\alpha}{\alpha-1}}-1\right) - \alpha(s-1)^{\frac{\alpha}{\alpha-1}}\right].$$

Note that this equation is reduced to (6) if $\alpha = 2$. If $\alpha > 2$, the maximum number of countries in a group will be less than three. (Indeed, it is two from the observation above.) If $\alpha < 2$, on the other hand, the maximum size of a coalition becomes greater. It is four if $\alpha = 1.15$. It is five if $\alpha = 1.1$. Although the size of a coalition is still small, this exercise shows that "three" is not necessarily *the* number.

4 Carbon Taxes vs. Emission Permit Trading

This section compares the two most-discussed policies that are aimed to prevent global warming, by relating them to the coalition formation under the two regimes, NTU and TU regimes. We show that international environmental cooperation to urge member countries to adopt carbon taxes is the same as forming a cooperation group under the NTU regime, and that international cooperation adopting emission permit trading is the same as group formation under the TU regime.

Suppose country i joins the environmental group S and adopt carbon taxes to abate pollution so as to maximize the joint welfare of the group. Country i selects a target g_i such that it maximizes the joint welfare $\sum_{j\in S} u_j$, and realizes its own welfare of $v_i(S)$. Country i has an incentive to join S if and only if $v_i(S; g_{-S}) - v_i(S\setminus\{i\}; g_i^{\{i\}}, g_{-S}) \geq 0$, which is exactly the same as the incentive constraint under the NTU regime. Therefore, we can regard the above analysis of group formation under the NTU regime as the analysis of international coordination with carbon taxes.

International emission permit trading within a group of countries corresponds to group formation under the TU regime; intra-group transfers can be designed by choosing an appropriate initial allocation of emission permit. Let E_i denote the total emission in country i when it makes no abatement effort. Also let e_i denote the resulting total emission in country i after emission permit is traded across countries in coalition S: e_i represents the total emission permit consumed by country i. Then, the abatement level of country i can be written as $g_i = E_i - e_i$. The group S can choose the total emission permit e such that $e = \sum_{j \in S}(E_j - g_j^S)$. The price of emission permit will be $p^S = m_S$, in which case all individuals in country i chooses $\tilde{g}_i$ such that the marginal abatement cost equals the price of permit, i.e., $\theta_i c'(\tilde{g}_i) = m_S$. This coincides with the first-order condition for the choice of g_i, shown in (3) in the previous section, so country i indeed abates pollution by g_i^S through the emission permit trading. Country i's total emission equals $e_i^S = E_i - g_i^S$, and hence country i's receipt from its sale of emission permit (or payment for its purchase of emission permit if it takes a negative value) equals $p^S(e_i^* - e_i^S)$, where e_i^* denotes the initial permit allocation for country i.

Having established the correspondence, we can draw on Proposition 2 to establish the following proposition.

Proposition 3 *The effectiveness of carbon taxes and emission permit trading are the same if countries are symmetric in the cooperation group. But emission permit trading is superior in inducing pollution abatement to carbon taxes if countries are asymmetric thanks to the incentive pooling effect.*

Before we conclude, let us examine the characteristics of the country that receives a large fraction of emission permit as an initial allocation. Consider a group of two countries, and assume for simplicity that the two countries evenly split the surplus that results from cooperation according to the Nash bargaining solution. It follows from (4) that the two countries' threat points are

$$v_1(\{2\}; g_1^{\{1\}}, g_{-\{1,2\}}) = \frac{m_1^3}{2\theta_1} + \frac{m_1 m_2^2}{\theta_2} + m_1 g_{-S},$$

$$v_2(\{1\}; g_2^{\{2\}}, g_{-\{1,2\}}) = \frac{m_2^3}{2\theta_2} + \frac{m_2 m_1^2}{\theta_1} + m_2 g_{-S},$$

respectively. Recall that the surplus to be split is given in (9) as

$$V(\{1,2\}; g_{-\{1,2\}}) - v_1(\{2\}; g_1^{\{1\}}, g_{-\{1,2\}}) - v_2(\{1\}; g_2^{\{2\}}, g_{-\{1,2\}}) = \frac{m_1 m_2}{2}\left(\frac{m_1}{\theta_2} + \frac{m_2}{\theta_1}\right).$$

Therefore, country 1's equilibrium payoff equals

$$U_1 = v_1(\{2\}; g_1^{\{1\}}, g_{-\{1,2\}}) + \frac{m_1 m_2}{4}\left(\frac{m_1}{\theta_2} + \frac{m_2}{\theta_1}\right),$$

and hence country 1's receipt from permit trading equals

$$U_1 - v_1(S; g_1^{\{1\}}, g_{-\{1,2\}}) = \frac{3m_1 m_2}{4}\left(\frac{m_2}{\theta_1} - \frac{m_1}{\theta_2}\right).$$

Similarly, country 2's receipt from permit trading equals

$$U_2 - v_2(S; g_2^{\{2\}}, g_{-\{1,2\}}) = \frac{3m_1 m_2}{4}\left(\frac{m_1}{\theta_2} - \frac{m_2}{\theta_1}\right).$$

Note that the sum of these receipt equals zero as it should be. Now, it is immediate that country 1 is a seller (or equivalently country 2 is a buyer) of emission permit if and only if $m_1\theta_1 < m_2\theta_2$. Recall that large and inefficient countries benefit more from group formation, or equivalently small and efficient countries benefit less. For the group to be immune to a unilateral deviation by a small country with efficient abatement technology, such a country must receive a positive rent.

Proposition 4 *Small countries with efficient abatement technology receive disproportionately high initial allocation of emission permit.*

5 Conclusion

In order to examine the size of stable environmental coalitions, we have constructed a model in which the size of the countries (and hence the collective preferences for the environment) and the abatement technology are different across the countries. We have derived free-riding-proof stable coalition such that no member country has an incentive to leave the coalition to get free-riding benefits and confirmed Barrett's (1994, 2001) results that the size of stable coalitions is rather small and internal transfers are effective in expanding stable coalitions. We have also shown that our NTU game is equivalent to carbon taxation while our TU game is equivalent to emission permit trading. Because the size of coalition is (weakly) larger under the TU game than under the NTU game when countries are asymmetric, we have concluded that the emission permit trading system is a superior system in this heterogeneous world.

There are many international environmental agreements in practice. Both theory and reality seem to suggest that realistic post-Kyoto environmental regime consists of multiple regional environmental agreements rather than a single worldwide agreement.

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