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Abstract

The transboundary pollution requires some kind of international cooperation. The international agreements for the environmental problems consume a large amount of time and laborious bargaining. Considering that the international agreement is not easily achieved for many types of environmental pollution and that a large part of pollution is related with economic activities of pollutants, environmental regulation using market is expected to bring about efficient solution. Employing a theory of voluntary provision of public goods, we propose a redistributional scheme to attain the efficient solution to abate transboundary pollution.

Keywords: Transboundary Pollution; Voluntary Provision of Public Goods; Subsidy and Tax Redistribution; Stackelberg Model

1. Introduction

Acid rain caused by economic activities of neighboring countries, water pollution in a going through some countries and an ocean pollution damaging ashore fishery on a large range are classified as transboundary pollution. The pollution appears to damage limited district to some extent and might be distinguished from global environmental problems. But the transboundary problems as well as the global environmental problems require international cooperation to abate effectively emission of pollutants. To investigate the transboundary pollution in the context of public economics, protecting or maintaining environment is assumed to be provision of public goods in neighboring countries.

The transboundary pollution involves complicated interests of some countries, a particular country could not directly decide any other country environmental policy such as regulation requirements, pollution tax and emission permit. These related countries should perform cooperative environmental policy from theoretical

perspective. The cooperation seems to be complemented by integration of environmental policy. The international coordination needs to spend a great amount of efforts and times. A non-cooperative abatement of pollution is practically expected to substitute the cooperative approach. On the other hand, the well-known prisoner's dilemma shows that the non-cooperative competition probably leads to inefficient consequences. To employ non-cooperative instruments for the transboundary pollution, we need carefully find out effective scheme.

Abatement of pollution is classified into public goods. Hoel (1990) points out that the theoretical results in voluntary provision of public goods are applicable to a solution in global warming agreement. Many authors such as Bergstrom, Blume and Varian (1986) argue the well-known result that voluntary provision could not achieve efficient provision in a Cournot-Nash framework. Although the negative results are widely accepted in public economics, Andreoni and Bergstrom (1996) propose a redistribution scheme by which efficient public goods is attained in the voluntary provision mechanism. Kirchsteiger and Puppe (1999) research further the redistribution scheme and demonstrates the existence of efficient provision by using non-cooperative Nash equilibrium analysis. They indicate the possibility that the efficient interior solution is unstable and easily replaced by inefficient boundary solution. The severe pollution in the international aspect might appear in this inefficient solution. In this paper, using the two-country model we propose a scheme that turns the inefficient solution into efficient one. It is argued that relatively advanced country should make a policy more benefiting for the less developed country so as to improve abatement of pollution.

This paper is organized as follows. In 2, the redistribution scheme is formulated for the environmental policy in the views of international repercussion. In 3, the condition of efficient abatement is defined and feature of the efficient solution is explained. Especially, as the population grows, the efficient abatement would be more likely to be achieved by lower tax rate. In 4 and 5, we investigate inefficient boundary solution and propose the international redistribution policy that turns inefficient abatement into efficient one. The existence of abatement is proved in 6. Applying the result of this paper, 7 states that environmental policy to initiate technological innovation is closely related with global industrial strategy for each government. The relationship between the environmental and industrial policy should be discussed in another opportunity.

2. Model

To simplify following argument, we consider two-country model. The two neighboring countries denoted by i and j are assumed to make an effort to abate

pollution. *i* stands for developed country and *j* states under or less developed country. In recent literatures of environmental economics, abatement of pollution is supposed to provide public goods. Representative individual of each country abates emission of pollutants g_i, $g_j (\geq 0)$ and the numbers of agents of country *i* and *j* are n_i, n_j. *n* represents the total number of individuals and is defined by

$$n = n_i + n_j. \tag{1}$$

i and j satisfy the inequalities,

$i \equiv h$, for all h, $1 \leq h \leq n_i$,

$j \equiv k$, for all k, $n_{i+1} \leq k \leq n$.

The total abatement of emission is depicted by

$$G = \sum_{h=1}^{n} g_h. \tag{2}$$

If individual of each country abate an identical abatement of pollution, (2) is simply written by

$$G = n_i g_i + n_j g_j. \tag{3}$$

Marginal abatement cost is 1. In more general case, the marginal cost of the two countries might not be identical. Since we investigate mainly efficient abatement of identical marginal cost countries, the identical marginal cost is supposed in this paper. Individual *i* and *j* consume a private good x_i, x_j. The private good is supposed to be a numeraire. The price is denoted by 1. The private good and the abatement of pollution are normal goods. Utility of *i*, *j* is expressed by

$$u_h(x_h, G), \text{ for } h = i, j. \tag{4}$$

The utility functions are assumed to be strictly concave and continuously differentiable. The marginal rate of substitution for *i* and *j* ($MRS_h \equiv -\dfrac{dx_h}{dG}$) are increasing with x_h and decreasing with *G*;

$$\frac{\partial MRS_h}{\partial x_h} > 0 \text{ and } \frac{\partial MRS_h}{\partial G} < 0 \text{[1]}.$$

It is assumed that at zero abatement the marginal rate of substitution is larger than marginal cost 1.

Both countries might manage cooperatively a subsidy and tax scheme to attain efficient abatement of emission. Each agent is privileged to accept subsidy and required to pay tax based on calculating formula under voluntary abatement

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[1] These inequalities are straightforward from

$$\frac{\partial MRS_h}{\partial x_h} = -\frac{u_{Gx} u_x - u_G u_{xx}}{[u_x]^2} > 0,$$

$$\frac{\partial MRS_h}{\partial G} = -\frac{u_{GG} - u_G u_{Gx}}{[u_x]^2} < 0.$$

u_{Gx}, u_x, u_G and u_{xx} mean partial derivative of utility function u_h, $h = i, j$.

distribution of individuals. Incomes of individuals i and j are initially endowed with m_i and m_j. Kirchsteiger and Puppe (1997) formulate a general linear form of subsidy and tax redistribution.

$$x_h + [1 - \sigma_h] g_h = m_h - \sum_{k \neq h}^{n} t_{hk} g_k, \quad h = 1, ..., n. \tag{5}$$

Abatement effort of individuals is supported by a rate $\sigma_h (0 \leq \sigma_h \leq 1)$ of subsidy and abatement costs of other individuals are partially shared by a constant rate $t_{hk} (0 \leq t_{hk} \leq 1)$ of tax. Budget equilibrium condition for the subsidy and tax scheme is represented by

$$\sum_{h=1}^{n} \sigma_h g_h = \sum_{h=1}^{n} \sum_{k \neq h}^{n} t_{hk} g_k. \tag{6}$$

Each individual is assured to obtain a positive post tax income. The condition is referred as no-bankruptcy and defined by

$$m_h - \sum_{k \neq h}^{n} t_{hk} g_k \geq 0, \quad h = 1, ..., n. \tag{7}$$

In the case that individuals of country i, j abate identical pollution g_i, g_j, the rate of subsidy are assumed to be equal to σ_i, σ_j for individual of country i, j. Suppose that government of country i founds the redistribution scheme to initiate abatement. The subsidy for abatement of i is probably financed through the tax on individuals of foreign country j as well as domestic country i. To consider the international repercussion we suppose the following environmental oriented tax system. The cost to equip facilities emitting lower pollution is partially subsidized by the government of county i. This environmental redistribution scheme taxes heavily on the individuals or firms using facilities to emit high pollution. The individuals or the products of firms targeted to tax inevitably include foreign inhabitants and imports from j. The tax on import products might rise the consumer price and decrease demand of the product. Consequently, the producers of j suffer the decline of revenue. That makes incomes of the individuals of j lower. Tax rate of i and j are denoted by t_{ii} and t_{ji} for g_i and t_{jj} and t_{ij} for g_j. Since we do not attempt to investigate tax incidence here, t_{ji} and t_{ij} represent only ex-post international effect of environmental redistribution policy. Subsidy and tax scheme (5) is separately rewritten for individuals of country i and j,

$$x_i + [1 - \sigma_i] g_i = m_i - [[n_i - 1] t_{ii} g_i + n_j t_{ij} g_j], \tag{8}$$

$$x_j + [1 - \sigma_j] g_j = m_j - [n_j t_{ji} g_i + [n_j - 1] t_{jj} g_j]. \tag{9}$$

The budget equilibrium condition of the scheme (6) is simply stated by

$$n_i \sigma_i g_i + n_j \sigma_j g_j = [[n_i - 1] n_i t_{ii} + n_i n_j t_{ji}] g_i + [n_i n_j t_{ij} + [n_j - 1] n_j t_{jj}] g_i. \tag{10}$$

(10) is transformed into

$$n_i [\sigma_i - [n_i - 1] t_{ii} - n_j t_{ji}] g_i + n_j [\sigma_j - n_i t_{ij} - [n_j - 1] t_{jj}] g_j = 0. \tag{11}$$

From the budget equilibrium condition (11), summing up (8) and (9) represents total budget condition

$$\sum_{h=i, j} n_h \left[x_h + g_h \right] = \sum_{h=i, j} n_h m_h \,. \tag{12}$$

Each country h could decide domestic subsidy and tax rate σ_h, t_{hh}, and t_{kh} and transfer budget surplus of h to k.

3. Efficient abatement of emission

In this section, we consider an efficient condition of abatement. For the first, representative individual of one country is assumed to obtain Nash conjecture. Individual h $(= i, j)$ maximizes (4) subject to budget constraint (8) or (9). Individuals consume positive private goods ($x_h > 0$). Individual i in the developed county could be willing to abate a positive pollution ($g_i > 0$). It is afraid in extreme case that j in the less developed country unfortunately could not afford to contribute abatement of pollution ($g_j \geq 0$).

Employing Lagrange multiplier λ, the first order conditions are stated by (12), (13), (14), (8) or (9) for $h = i, j$.

$$\frac{\partial u_h}{\partial x_{hi}} - \lambda_h = 0 \,, \tag{12}$$

$$\frac{\partial u_h}{\partial G} = \lambda_h \left[\left[1 - \sigma_h \right] + \left[n_h - 1 \right] t_{hh} \right] \leq 0 \,, \tag{13}$$

$$g_h \left[\frac{\partial u_h}{\partial G} - \lambda_h \left[\left[1 - \sigma_h \right] + \left[n_h - 1 \right] t_{hh} \right] \right] = 0 \,. \tag{14}$$

(13) satisfies equality, and directly derives (14) for i. (14) is not independent for i. Regarding j, it is possible that (13) hold with the strict inequality. In this boundary solution, (14) is the independent equation. Let us consider this corner solution later on, we suppose that (g_i, g_j) is the interior solution for a while. The interior solution satisfies Samuelson efficient condition for the abatement of pollution;

$$n_i \frac{\dfrac{\partial u_i}{\partial G}}{\dfrac{\partial u_i}{\partial x_i}} + n_j \frac{\dfrac{\partial u_j}{\partial G}}{\dfrac{\partial u_j}{\partial x_j}} = \sum_{h=i, j} n_h \left[\left[1 - \sigma_h \right] + \left[n_h - 1 \right] t_{hh} \right] = 1 \,. \tag{15}$$

Reminding that $\left[1 - \sigma_h \right] + \left[n_h - 1 \right] t_{hh} > 0$ for each h, the necessary condition for (15) is

$$\left[1 - \sigma_h \right] + \left[n_h - 1 \right] t_{hh} \leq \frac{1}{n_h} \,, \text{ for } h = i, j \,. \tag{16}$$

(16) is interpreted as follows. As population of each country increases, addition of own share rate of par capita abatement cost $\left[1 - \sigma_h \right]$ and total tax rate of own country $\left[n_h - 1 \right] t_{hh}$ must be set lower to attain efficient allocation.

For the next, we consider the equilibrium budget condition of subsidy and tax

scheme. From rearrangement of (15)

$$n_j \sigma_j - n_j [n_j - 1] t_{jj} = n_j - 1 + n_i [[1 - \sigma_i] + [n_i - 1] t_{ii}], \tag{17}$$

is obtained. To substitute (17) into (11),

$$\frac{g_i}{g_j} = -\frac{n_j - 1 + n_i [[1 - \sigma_i] + [n_i - 1] t_{ii}] - n_i n_j t_{ij}}{n_i [\sigma_i - [n_i - 1] t_{ii} - n_j t_{ji}]}. \tag{18}$$

follows. Suppose that the developed county i pays overpayment which subtract the subsidy from the payment in this redistribution scheme. The denominator of (18) is negative. (18) is positive for interior solution, therefore the numerator must be positive. From $[1 - \sigma_h] + [n_h - 1] t_{hh} > 0$ the sufficient condition of efficiency yields

$$n_j - 1 - n_i n_j t_{ij} > 0. \tag{19}$$

From the signs of the denominator and (19),

$$\frac{\sigma_i - [n_i - 1] t_{ii}}{n_j} < t_{ji}, \tag{20}$$

$$\frac{1}{n_j} = \frac{n_j - 1}{n_i n_j} > t_{ij}, \tag{21}$$

are satisfied so that the two country voluntarily abate pollution for a positive amount. The interpretation of (20) is that individual of advanced country i should share sufficiently own abatement cost (t_{ii}). In addition, as the population ratio of the advanced country to the less developed country rises to extremely high, the constraint of (20) becomes less restrictive. (21) implies that the larger the population of both country become, the less cost share of i due to the less developed country should be set.

4. Improving abatement for an inefficient solution

In transboundary pollution, some polluting countries could not attain an efficient abatement for the shortage of technology and money. In the previous model, the boundary solution $(g_i > 0, g_j = 0)$ states an inefficient abatement. In this boundary solution, for j (13) holds with strict inequality. Hence, the value of (15) is strictly less than one. Samuelson efficient condition is not satisfied. In this inefficient case, from budget equilibrium condition (11) the equality;

$$\sigma_i - [n_i - 1] t_{ii} - n_j t_{ji} = 0, \tag{22}$$

is derived. The tax rate of the less developed country j (t_{ji}) is not assumed to be zero. Suppose that the redistribution tax of country i is charged in lump sum on some commodities. The commodities are exported to the country j and the people of j purchase those at a price including the lump sum tax. The effect of redistribution scheme of the country i spills over the other country j. But the effect is too restrictive for the government i to achieve the efficient allocation. Even if the developed country constructs one own subsidy and tax scheme for abatement, efficient

abatement could not be obtained by the single country. To improve efficiency, a favorable approach is that j raises subsidy rate σ_j or lower tax rate t_{jj}. An interior solution is probably obtained. The boundary solution will be simply substituted with interior one. However, j owns the right to alter domestic rates of subsidy σ_j and tax t_{jj}. Therefore, it is not necessary that j alters efficiently its domestic rate as i intend to be. The less developed country j is easily supposed to prefer consumption of private goods to abatement of pollution. By dividing (13) by (12), the boundary solution shows that the marginal rate of substitution of abatement for the private good is less than the marginal cost of abatement after the redistribution tax. In this context, j is not willing to adopt the scheme planed by i to abate pollution, but sustain the way to assure more economic profits. The inefficient corner solution remains.

5. A bargaining solution and a redistribution scheme

In this paper, we consider the international abatement where the cooperative redistribution scheme is not well established. When the abatement of pollution is the inefficient boundary solution stated above, the more developed country would be required to contribute positively to the improvement of abatement. However, it is only an optimistic perspective that the international abatement program planed and executed by the more developed country could show the expected performance. Even if the more developed country makes a plan to increase abatement, it is unfortunately possible that international abatement will not appear to increase abatement. We must make clear the possibility that the more developed country induces the less developed country to increase abatement of pollution.

We adapt Stackelberg model for the international abatement of pollution. The more developed country i is the leader. The less developed country j is the follower. i could arrange coefficients of the redistribution scheme for own country σ_i, t_{ii}, t_{ij}. The coefficient regarding j, σ_j, t_{jj}, t_{ji} are exogenous for i. Figure 1 and 2 illustrate the optimal consumption for the country i and j.

Initially, suppose that j is not willing to abate pollution. The abatement vector of i and j is a boundary solution $(n_i g_i^*, 0)$. This solution is expressed by the point A's in the two Figures. Country i lowers the cost share t_{ji} of j to t'_{ji}. (22) is transformed into

$$n_j t'_{ji} = \sigma'_i - [n_i - 1]t'_{ii}. \tag{23}$$

The decrease of cost share for j ($n_j t_{ji}$) increases the slope of the budget constraint line of i with a constant income m_i. The budget line of i turns downward clockwise. Using the first order condition of abatement and the assumption of normal goods for abatement, it is straightforward from the income effect that the optimal abatement of i ($n_i g_i^*$) decreases to $n_i g_i^{**}$. The optimal point A in Figure 1 is replaced by the point

B.

For the second step, since the post tax income of j ($m_j - n_i t_{ji} g_i^{**}$) increases in (9), the marginal substitution regarding j rises for the relatively small abatement $n_i g_i^{**}$ from the income effect. (13) is possibly satisfied with equality ($h = j$) for a positive $n_j g_j^{**}$. We consider the interior solution $\left(n_i g_i^{**}, n_j g_j^{**} \right)$. In (11) positive coefficient of $n_i g_i$ for the positive $n_j g_j^{**}$. As the tax share of j ($n_j t_{ji}$) decreases over certain point, the coefficient of g_i might be positive. In this case, the negative coefficient of g_j means decrease of $\sigma_j - [n_j - 1] t_{jj}$ or increase of $n_i t_{ij}$. The slope of budget line for j becomes steeper or a part of abatement cost in j is taxed on i. A part of income in country i is redistributed to j. The income effect in the country j the boundary optimal point A in Figure 2 might move upwardly to the interior optimal point B. Consequently, the positive abatement of j moves point B in Figure 1 to an efficient point C.

6. Existence of efficient abatement

The explanation in the previous section roughly illustrates the process that the boundary solution turns into interior one. In this section, we thoroughly inquire into improving efficiency of abatement in the context of theoretical analysis. $\left(g_i^*, 0 \right)$ means $G = n_i g_i^{**} + 0$. x_i and x_j are expressed by a function of t_{ij} and t_{ji}. Using the budget condition (8) and (9), for the boundary solution (12) and (13) are restated by

$$MRS_i \left(n_i g_i^*, x_i^*; t_{ij} \right) = 1 - \sigma_i + [n_i - 1] t_{ii},$$
$$MRS_j \left(n_j g_j^*, x_j^*; t_{ji} \right) < 1 - \sigma_j + [n_j - 1] t_{jj}.$$

To state simply, constant parameters m_i, m_j, n_i, n_j are omitted. MRS_h stands for marginal rate of substitution of G regarding x_h for h ($= i, j$). We are mainly concerned with redistribution policies for inefficient abatements. Since the abatement of the boundary solution is inefficient, we suppose that an efficient abatement exists. The existence condition for efficient abatement ensure a participation condition for i and j,

$$u_h \left(n_i g_i^{**} + n_j g_j^{**}, x_h^{**} \right) \geq u_h \left(n_i g_i^* + n_j g_j^*, x_h^* \right), \quad h = i, j. \tag{24}$$

In the boundary solution $g_j = 0$ is satisfied. (9) is transformed into

$$x_j = m_j - n_j t_{ji} g_i. \tag{25}$$

Substituting (22) into (8), the budget constraint for i is arranged into

$$x_i + [1 - n_j t_{ji}] g_i = m_i. \tag{26}$$

Using (25) and (26),

$$\frac{dx_i}{dt_{ji}} = -[1 - n_j t_{ji}] \frac{dg_i}{dt_{ji}} + n_j g_i,$$

$$\frac{dx_j}{dt_{ji}} = -\left[n_j t_{ji} \frac{dg_i}{dt_{ji}} + n_j g_i \right]$$

are obtained. When t_{ji} decreases, the post tax price of abatement ($1 - n_j t_{ji}$) increases. Since the abatement is normal goods, consumption of abatement decreases. That is, $\frac{dg_i}{dt_{ji}} > 0$ is obtained. It is straightforward that $\frac{dx_j}{dt_{ji}} < 0$ is satisfied.

Differentiating MRS_j with t_{ji},

$$\frac{dMRS_j}{dt_{ji}} = n_i \frac{\partial MRS_j}{\partial G} \frac{dg_i}{dt_{ji}} + \frac{\partial MRS_j}{\partial x_j} \frac{dx_j}{dt_{ji}} \tag{27}$$

is derived. Since MRS_i and MRS_j are decreasing with G and increasing with x_i or x_j, it is assured that (27) is negative. As t_{ji} decreases, MRS_j rises monotonously. Suppose that g_j remains zero. When t_{ji} approaches to zero, the absolute slope of budget constraint (26) becomes approximately equal to 1. Remaining that MRS_j is continuous with G, MRS_j is greater than 1 for sufficiently small G from the assumption with MRS_j. If subsidy rate is large enough, or if tax rate is small enough, inequality $1 - \sigma_j + \left[n_j - 1 \right] t_{jj} < 1$ is derived. For some G^{**} to satisfy (23) for j

$$MRS_j = 1 - \sigma_j + \left[n_j - 1 \right] t_{jj}$$

could be obtained. However, i never decide to lower t_{ji} so much. Because to lower t_{ji} means to decreases consumption of abatement G and private good x_i at zero abatement of j ($g_j = 0$) and at sufficiently large g_i. In this case, lowering t_{ji} contradicts the participation condition from $\frac{dg_i}{dt_{ji}} > 0$ and $\frac{dx_j}{dt_{ji}} > 0$. If the country i propose to increase t_{ji}, the income effect decreases utility of the country j. To avoid such a proposal of i, the country j should decide to abate in order to attain an allocation satisfying (24).

An interior solution could be achieved the redistribution scheme stated in this paper. We complete the existence proof of the efficient solution.

7. A Condition for an efficient abatement

In previous section, we have argued that redistributional scheme in the model has the international effect and efficient abatement of transboundary pollution could be achieved even if individual j in less developed country could not contribute the abatement. It was also shown that relevant value of t'_{ji} should be employed to attain this interior solution. In this section, we examine the model in detail to derive such t'_{ji} that ensures the existence of efficient abatement.

To simplify the analysis, it is assumed that individuals of each country has Cobb-Douglas utility function

$$u_i(x_i, G) = x_i^\alpha G^{1-\alpha}, \quad 0 < \alpha < 1, \; i,$$

$$u_j(x_j, G) = x_j^\beta G^{1-\beta}, \quad 0 < \beta < 1, \; j.$$

Since individuals of country i contribute positive amount of abatement, the first order conditions are described as

$$\alpha x_i^{\alpha-1} G^{1-\alpha} - \lambda_i = 0,$$

$$n_i [1-\alpha] x_i^\alpha G^{-\alpha} - \lambda_i [1 - \sigma_i + [n_i - 1] t_{ii}] = 0.$$

On the other hand, individual of country j is supposed not to contribute, it implies that equation (13) holds with inequality. First order condition for j is given as

$$\beta x_j^{\beta-1} G^{1-\beta} - \lambda_j = 0,$$

$$n_j [1-\beta] x_j^\beta - \lambda_j [1 - \sigma_j + [n_j - 1] t_{jj}] < 0,$$

$$g_j \left[n_j [1-\beta] x_j^\beta G^{-\beta} - \lambda_j [1 - \sigma_j + [n_j - 1] t_{jj}] \right] = 0.$$

These conditions give a corner solution

$$x_i^* = \alpha m_i, \quad g_i^* = \frac{[1-\alpha] m_i}{1 - \sigma_i + [n_i - 1] t_{ii}},$$

$$x_j^* = m_j - \frac{n_i t_{ji} [1-\alpha] m_i}{1 - \sigma_i + [n_i - 1] t_{ii}}, \quad g_j^* = 0. \tag{25}$$

From assumption, t_{ji} in (25) is not zero.

At this corner solution, the government of i is supposed to lower t_{ji} to achieve efficient abatement of pollution. It is given in equation (23). When (23) applies, decision problem of individual i is described by

$$\max \quad u_i(x_i, G) = x_i^\alpha G^{1-\alpha}$$

$$\text{s.t.} \quad x_i + [1 - n_j t'_{ji}] g_i = m_i,$$

$$G = n_i g_i.$$

We could obtain

$$x_i^{**} = \alpha m_i, \quad g_i^{**} = \frac{[1-\alpha] m_i}{1 - n_j t'_{ji}}. \tag{26}$$

From (26), $g_i^{**} < g_i^*$ is confirmed. Since g_i^{**} is assumed to be positive,

$$1 - n_j t'_{ji} > 0$$

holds.

While individual i reduces the contribution, due to lowered tax rate, it is possible that individual j starts to contribute positive amount of abatement. To observe this, note that maximization of j is

$$\max \quad u_j(x_j, G) = x_j^\beta G^{1-\beta}$$

$$\text{s.t.} \quad x_j + [1 - \sigma_j + [n_j - 1] t_{jj}] g_j = m_j - n_i t'_{ji} g_i^{**},$$

$$G = n_i g_i^{**} + n_j g_j,$$

$$g_j > 0.$$

Solving this,

$$x_j^{**} = \frac{\begin{vmatrix} n_i\beta[1-\sigma_j+[n_j-1]t_{jj}]g_i^{**} & -n_j\beta[1-\sigma_j+[n_j-1]t_{jj}] \\ m_j - n_i t'_{ji} g_i^{**} & [1-\sigma_j+[n_j-1]t_{jj}] \end{vmatrix}}{\begin{vmatrix} n_i[1-\beta] & -n_j\beta[1-\sigma_j+[n_j-1]t_{jj}] \\ 1 & [1-\sigma_j+[n_j-1]t_{jj}] \end{vmatrix}},$$

$$g_j^{**} = \frac{\begin{vmatrix} n_i[1-\beta] & n_i\beta[1-\sigma_j+[n_j-1]t_{jj}]g_i^{**} \\ 1 & m_j - n_i t'_{ji} g_i^{**} \end{vmatrix}}{\begin{vmatrix} n_i[1-\beta] & -n_j\beta[1-\sigma_j+[n_j-1]t_{jj}] \\ 1 & [1-\sigma_j+[n_j-1]t_{jj}] \end{vmatrix}} \tag{27}$$

are obtained. From the assumption of non-bankruptcy and value of each parameter, $x_j^{**} > 0$ could be seen. However, the sign of g_j^{**} could not be determined. We now consider the condition to hold $g_j^{**} > 0$.

If efficient interior solution is achieved, from Samuelson condition,

$$n_i[1-\sigma'_i+[n_i-1]t'_{ii}] + n_j[1-\sigma_j+[n_j-1]t_{jj}] = 1 \tag{28}$$

must hold. (23) is used to substitute into (28) gives

$$1-\sigma_j+[n_j-1]t_{jj} = \frac{1-n_i[1-n_j t'_{ji}]}{n_j} \tag{29}$$

Since it is supposed that left-hand of (29) is positive, inequality

$$1-n_i[1-n_j t'_{ji}] > 0. \tag{30}$$

is satisfied. Substituting (29) into (27) gives

$$g_j^1 = \frac{n_i n_j[1-\beta]m_j[1-n_j t'_{ji}] - n_i^2 n_j[1-\alpha][1-\beta]m_i t'_{ji} - n_i[1-\alpha]\beta m_i[1-n_i[1-n_j t'_{ji}]]}{[n_i[1-\beta]+n_j\beta][1-n_j t'_{ji}][1-n_i[1-n_j t'_{ji}]]}. \tag{31}$$

From $n_i, n_j \geq 1$, $0 < \beta < 1$ and (30), the denominator of (31) is positive. To hold $g_j^{**} > 0$, it is required that the numerator of this equation should be positive. Arranging gives

(Numerator=)

$$-n_i n_j[n_i[1-\alpha]m_i + n_j[1-\beta]m_j]t'_{ji} + n_i[n_j[1-\beta]m_j - [1-n_i][1-\alpha]\beta m_i]. \tag{32}$$

(32) is linear in t'_{ji}. It could be seen that its gradient is negative and its intercept is positive. Therefore there exists some t'_{ji} such that $g_j^{**} > 0$. The government of

country i can choose $t'_{ji} \in \left(0, \dfrac{n_j[1-\beta]m_j - [1-n_i][1-\alpha]\beta m_i}{n_i[1-\alpha]m_i + n_j[1-\beta]m_j}\right)$ to attain the interior

solution.

7. Concluding remarks

A large amount of researches are published in the field of transboundary pollution. Hoel (1997) contrasts coordination with non-coordination of environmental policy. Generally, the coordination of environmental policy is expected to bring about profitable results for transboundary pollution. The coordination of environmental policies is not easily achieved between different types of countries. In some cases, the coordination seems to need a complicated arrangement of conflicting national interests. Most of transboundary pollutions are derived from economic activities in neighboring countries. In the international free trade system, economic activities are operated under the rule of international market mechanism. The effective policies to control market activities affect abatement of transboundary pollution indirectly or unintended. The indirect solution through market mechanism is practical policies for abatement of transboundary pollution. Silva (1997) discusses optimal environmental policy considering mobility of population. In international economies, mobility of population is largely restricted by most countries. The redistributional scheme considered in this paper could control transboundary pollution through the international market economy.

International redistribution of income such as economic aid is helpful for developing many underdeveloped countries. We could suppose that a international redistributional scheme is an alternative to improve abatement of global pollution. We make clear that the more developed country could induce the less developed country to take cooperative environmental policy by using a redistributional tax scheme. Since some environmental tax policies are designed to initiate innovation of environmental technology, these policies might work as the redistributional policy. Considering the research regarding international industrial policy (Spencer and Brander (1982)), the international welfare analysis remains as a problem to investigate. As Epple and Romer (1996) points out, it is remained also unclear that a political decision is consistent with the efficient abatement scheme.
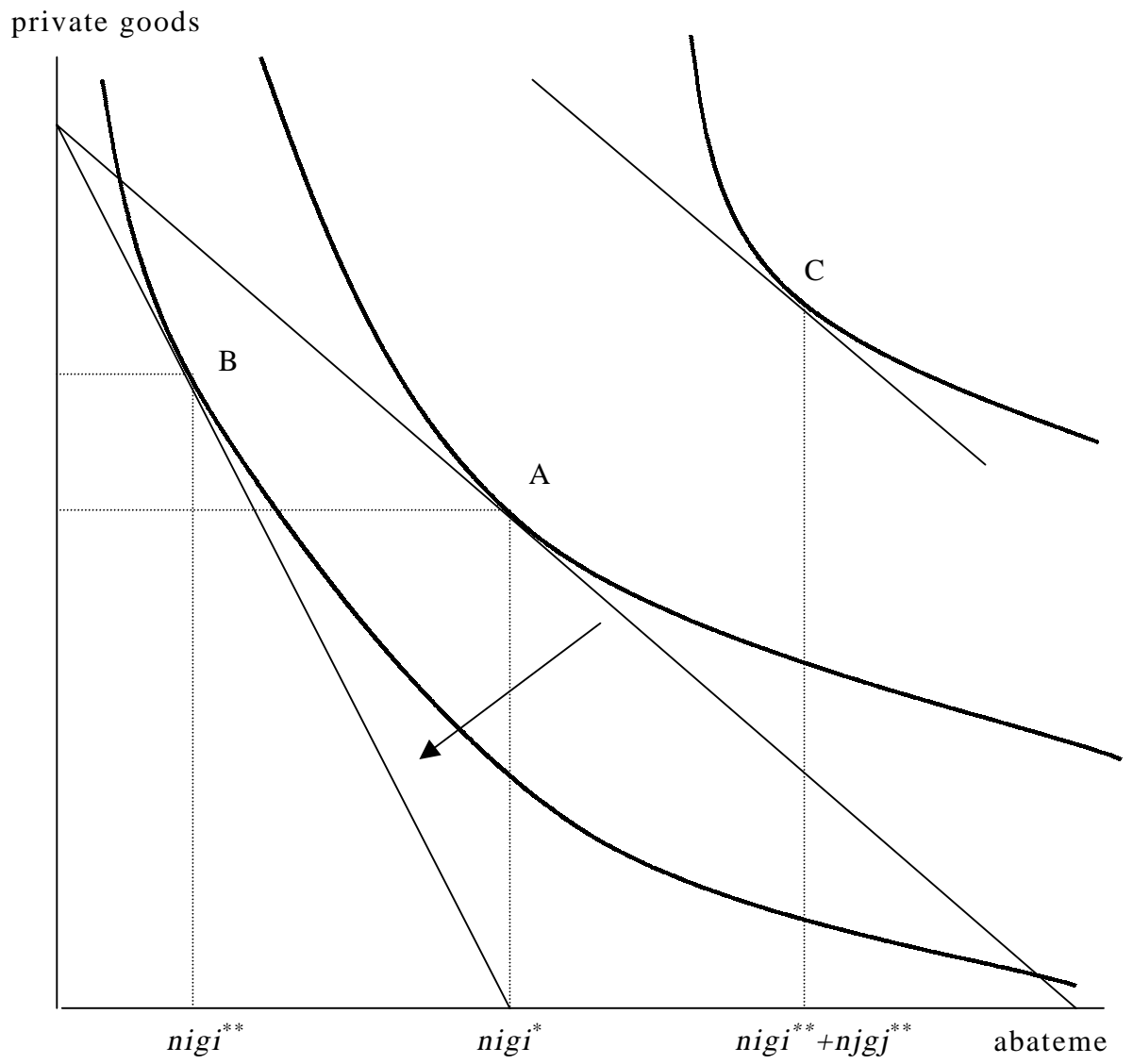
private goods

B

A

C

$nigi^{**}$ $nigi^*$ $nigi^{**}+njgj^{**}$ abateme

Figure 1 Voluntary abatement of advanced country i

13

private goods
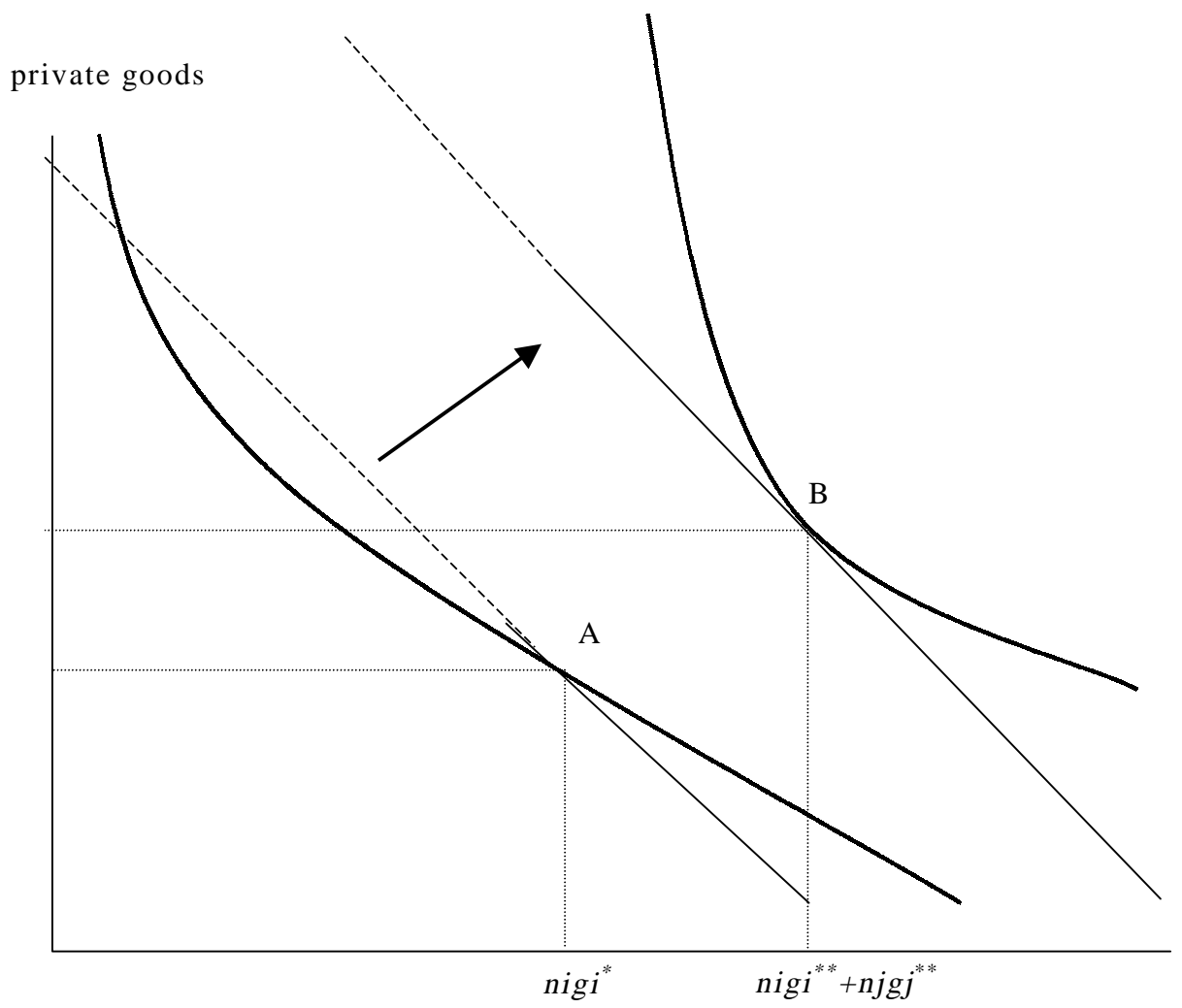
A

B

$nigi^*$ $nigi^{**}+njgj^{**}$

Figure 2 Voluntary abatement of developing country j

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