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Abstract

This paper investigates the welfare effects of international transfers of environmental technologies in open economies with international oligopoly and transboundary pollution, and shows that policy differentiation between the donor and recipient countries and/or product differentiation between the donor and recipient firms play a critical role in obtaining a bilateral agreement on the transfer policy between nations. The results arise from the fact that policy differentiation weakens the strategic relationships in environmental policy setting between governments and that product differentiation weakens the strategic relationships in quantity choices between firms.

Keywords: Technology Transfer; Environmental Tax; Oligopoly
JEL Classification: F18; H23

1 Introduction

The relationship between environmental policies and trade liberalizations has been receiving increasing practical and academic attention. Some economists indicate that the trade globalization may provide countries with an incentive to relax their environmental policies for fear of disadvantaging domestic industries.[1] This tendency of the 'race to the bottom' in an environmental policy setting makes it difficult for countries to multilaterally cooperate in tackling global environmental problems.

Recently, the transfer of superior environmental technologies to less-advanced countries has been considered an effective policy in confronting international environmental problems such as global warming. The reason for this is that the transfer of clean technologies may improve the environment and welfare not only in the recipient country but also that in the donor country

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[1]For a detailed discussion, see Barrett (1994), Willson (1996), Rauscher (1997), and Ulph (1999) among several others.

through the decreases in transboundary pollution. In fact, for instance, the Clean Development Mechanism (CDM) in Kyoto Protocol encourages the Annex I Parties (developed countries) to transfer their low carbon technologies to non-Annex I Parties (developing countries) in order to obtain credits for greenhouse gasses. Another example is that Japan has increased the amount of bilateral technical cooperation in its environmental Official Development Assistance (ODA).[2]

Can international transfers of environmental technologies actually lead to Pareto-improving outcomes? Various studies have been conducted on this issue through the application of the model of private provision of public goods. This type of literature considers the global environment as a public good to which each government voluntarily contributes by reducing emissions.[3] Buchholz and Konrad (1994) and Ihori (1996) have shown that countries might have an inventive to adopt *inefficient* environmental technologies even if more efficient technologies were available at no charge. This seemingly paradoxical result arises from the strategic relationship between governments: The adoption of superior emission technologies by one country induces other countries to free ride and increases their emissions (i.e. decreases their contributions). In the context of environmental technology transfers, the result implies that the transfer policy may not be Pareto-improving, since the transfer might reduce the welfare of the recipient country. Subsequently, constructing a model where a technologically advanced country can decide the amount of technology transfers to the less-advanced country prior to the contribution stage, Stranlund (1997) indicated that technology transfer might be Pareto-improving. Likewise, Lee (2001) pointed out that technology transfer may reduce the welfare of the recipient country in the case of the global environment being a pure public good, whereas it may be Pareto-improving if the global environment is an impure public good. Recently, Hattori (2005) showed that technology transfer would be beneficial for both countries if the private and public goods (the environment) are complementary for consumers.

However, these studies have not considered the manner in which each government contributes to public goods (the manner of controlling the emissions) since they have concentrated on the strategic interactions between the governments. In addition, they have not captured the strategic behavior of firms or the interactions of international markets despite the fact that the governmental policy for reducing emissions necessarily affects the behavior of firms. Considering the strategic interactions of the international market may affect the welfare result of international transfer of environmental technologies.

In order to address these questions, we construct a three-stage game with international trade and transboundary pollution and investigate the welfare effects of the international transfers of environmental technologies.[4] The model developed here consists of two countries, each having

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[2]According to Japan's Official Development Assistance Annual Report 2006, the number of trainees accepted from the developing countries has increased from 1,192 in 1994 to 2,162 in 2005, and the number of projects related to environmental technology cooperation to the developing countries has also increased from 47 in 2000 to 169 in 2005.

[3]For more detailed investigations, extensions, and applications of the private provision of public goods, see Cornes and Sandler (1996). Further, for an early research on the application of strategic environmental relations between governments, see Hoel (1990).

[4]By constructing an open-economy model with international competition and environmental externality, Barrett (1994), Kennedy (1995), Rauscher (1997), and Ulph (1999) conducted analyses on strategic environmental policies in various international contexts. However, these studies failed to analyze the welfare effects of envi-

one representative firm. In the first stage (diplomatic policy stage), the government decides whether or not to offer the transfer of environmental technologies to the foreign government. If they do, then the foreign government decides whether or not to accept the offer. In the second stage (domestic policy stage), each government simultaneously sets domestic environmental (emission) taxes. In the third stage (Cournot competition stage), each firm competes in the world market in Cournot fashion, given the policies in both the countries. The pollution arises from production and could be transboundary. Such model structures enable us to investigate the welfare effects of technology transfer not only through intergovernmental policy relationships but also through the market interactions between firms.

Within this framework, we first investigate the welfare effects of the transfer in the case of both firms selling homogenous products as a benchmark case. Further, the model is extended by incorporating two types of differentiations: policy and product differentiations. In order to directly investigate the effect of policy differentiation on the results of the technology transfer, we consider the case in which the emission subsidy as a policy tool is prohibited and one country levies the emission taxes on a domestic firm whereas the other country does not. Subsequently, we consider the case where firms produce differentiated goods in the world market.

The results of the analysis reveal that the policy and product differentiations play important roles in ensuring that the transfer policy leads to Pareto-improvement. In contrast, if there are only a few differences in the qualities produced or the policies implemented between the donor and the recipient, the bilateral agreement on the transfer will not be established. The results are based on the following reasons. Technology transfer not only induces the recipient government to relax its domestic environmental policies but also induces the recipient firm to increase the outputs, which provides the donor government negative incentives for transfer due to the strategic relationships in policy and production choices. However, the policy differentiation weakens the strategic relationships in the policy setting between the countries, and moreover, the product differentiation weakens the strategic relationships in quantity setting between the firms. In other words, the two differentiations reduce the negative transfer incentives for the donor, and hence, may encourage technology transfers.

The remainder of the paper is organized in the following manner. In the next section, we construct the basic model in which both the representative firms produce homogenous goods, and we investigate the welfare implications of transferring the environmental technologies. In order to clearly demonstrate the importance of policy asymmetry between countries with respect to the results, Section 3 considers the case of policy asymmetry where the implementation of emission subsidies is prohibited. In Section 4, the product differentiation is considered as well. In the last section, we conclude the paper and provide directions for future work.

2 The Benchmark Model

Consider two firms, 1 and 2, that produce homogenous products and are located in two different countries, 1 and 2, respectively. Each firm $i \in \{1, 2\}$ engages in Cournot (quantity) competition

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ronmental technology transfer among nations. See Requate (2006) for further details regarding environmental policies under imperfect competition.

in a world market. Production of goods requires domestic labor l_i using linear technology $q_i = l_i$, where q_i is the output of firm i. In the production process, firms generate pollution which is proportional to their output, that is, firm i's emissions are given by $\delta_i q_i$, where δ_i is the emission coefficient of firm i. Profits of firm i are defined as:

$$\Pi_i = P(Q)\,q_i - w_i\,l_i - \delta_i\,q_i\,t_i, \qquad \forall\,i \in \{1,2\}, \tag{1}$$

where $P(Q)$ is the inverse demand in the world market $(Q = \sum_i q_i)$, w_i is the wage rate of country i, and t_i is the rate of emission tax imposed in country i.

In order to alleviate the environmental damages from emissions, each government i can impose an emission tax (or subsidy) t_i on the domestic firm. However, each country suffers not only from the domestic firm's emissions but also from the foreign firm's emissions since the emissions possess a transboundary property. Thus, the total emissions in country i, E_i, are given by:

$$E_i = \delta_i q_i + \gamma \delta_j q_j, \quad \forall\,i,j \in \{1,2\},\ i \neq j, \tag{2}$$

where $\gamma \in [0,1]$ measures the degree of transboundary pollution. Perfectly domestic (global) pollution is characterized by $\gamma = 0$ $(\gamma = 1)$.[5]

Welfare of country i is defined as the sum of firm i's profit, the tax revenue, and the disutility from emissions in country i:

$$W_i = \Pi_i + R_i - D_i(E_i), \quad \forall\,i \in \{1,2\}, \tag{3}$$

where $R_i = \delta_i q_i t_i$ is the tax revenue of government i, and $D_i(\cdot)$ is the environmental damage cost (D is assumed to be increasing and convex with $D(0) = 0$).

We consider the following three-stage game: In stage 1, as a diplomatic policy, the government in the country where the firm with a relatively superior environmental technology is located decides whether or not to offer the transfer of the environmental technologies to a foreign firm. If they do, the foreign government decides whether or not to accept the offer. In stage 2, each government simultaneously decides its domestic environmental policy, namely, setting an environmental tax rate. In stage 3, each firm chooses the output, given the environmental technologies and taxes.

2.1 Stage 3: Cournot competition

The model is solved backwards. Profit maximization of firm i yields the first-order condition:

$$P + P'q_i - w_i - \delta_i t_i = 0, \quad \forall\,i \in \{1,2\}, \tag{4}$$

which determines the equilibrium output of firm i as $q_i(\cdot) = q_i(t_i, t_j, \delta_i, \delta_j; w_i, w_j)$, $\forall\,i,j \in \{1,2\}$, $i \neq j$.

Lemma 1

The equilibrium output in the third stage has the following properties:

$$\frac{\partial q_i}{\partial t_i} < 0,\ \frac{\partial q_i}{\partial t_j} > 0,\ \frac{\partial q_i}{\partial \delta_i} < 0,\ \frac{\partial q_i}{\partial \delta_j} > 0,\ \frac{\partial q_i}{\partial w_i} < 0,\ \frac{\partial q_i}{\partial w_j} > 0, \quad \forall\,i,j \in \{1,2\},\ i \neq j.$$

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[5]In other words, emissions are pure private bads for countries if $\gamma = 0$ and are pure public bads if $\gamma = 1$.

Proof: See Appendix.

The third-stage equilibrium outputs, which have the standard property of a Cournot oligopoly setting, are decreasing in the own taxes, emission coefficients, and wages and increasing in those of the rival.

Substituting the equilibrium output into the profit function yields the equilibrium profit in the third stage represented by $\Pi_i(\cdot) = \Pi_i(q_i(\cdot), q_j(\cdot), t_i, \delta_i)$.

2.2 Stage 2: Domestic policy choices in environmental taxes

In stage 2, each government sets the emission taxes so as to maximize its national welfare. By using the envelope theorem, the first-order conditions of welfare maximization are obtained as below:

$$\underbrace{\frac{\partial \Pi_i}{\partial q_j}\frac{\partial q_j}{\partial t_i} - \delta_i q_i}_{(-)} + \underbrace{\frac{\partial R_i}{\partial t_i} + \frac{\partial R_i}{\partial q_i}\frac{\partial q_i}{\partial t_i}}_{(+) \text{ or } (-)} - \underbrace{D'(\cdot)\left[\frac{\partial E_i}{\partial q_i}\frac{\partial q_i}{\partial t_i} + \frac{\partial E_i}{\partial q_j}\frac{\partial q_j}{\partial t_i}\right]}_{(+)} = 0. \quad \forall i, j \in \{1, 2\},\ i \neq j. \quad (5)$$

The first under-braced term in (5) captures the *profit-shifting effects* of environmental taxes, which consist of two parts: strategic and cost-raising effects. The former refers to the effect brought about by imperfect competition, and the latter is the direct effect of taxes on the marginal cost of production. Since both of these effects are negative, each government has an incentive to reduce taxes in order to gain profits.

The second under-braced term in (5) captures the *revenue-raising effects* of environmental taxes, which also consist of two parts: direct and indirect effects. The former is positive, while the latter is negative; this is because the increases in taxes shrink the domestic production. After all, the revenue-raising effects are positive (negative) if the tax elasticity of the output is less (more) than unity.[6]

The third under-braced term in (5) captures the *pollution-reducing effects* of environmental taxes. The square bracket following the marginal damage D' represents the variation of emissions through the changes in their own tax rate. The first term in the square bracket represents decreases in emissions by shrinking its firm's output, and the second term represents an increase in emission by increasing the other firm's output. In the case of the absence of emission spillovers ($\gamma = 0$), the second term reduces to zero. In this case, the pollution-reducing effects are necessarily positive. The larger the value of γ, the greater the emission spillovers as a result of the increase in other firm's output. We confirm that in the case of linear demand, the pollution-reducing effects become positive for $0.5\delta_j < \delta_i < 2\delta_j\ \forall\ i \in \{1, 2\}, i \neq j$. Throughout the paper, we assume the following:

Assumption 1 $0.5\delta_j < \delta_i < 2\delta_j\ \forall\ i \in \{1, 2\}, i \neq j$.

The assumption indicates that the emission efficiencies are not extremely differentiated between firms to the extent that the pollution-reduction effects become negative.

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[6]Using the tax elasticity of output $\epsilon_t^{ii} \equiv -\frac{\partial q_i}{\partial t_i}/\frac{q_i}{t_i}$, the revenue-raising effects can be rewriten as $\delta_i q_i(1 - \epsilon_t^{ii})$.

As a result, each government sets a positive environmental tax rate when the positive pollution-reducing effects dominate a sum of the negative profit-shifting effects and positive/negative revenue-raising effects.

To make the analysis simple, we further assume that both the inverse demand function and the environmental damage function are linear.

Assumption 2 $P'' = D'' = 0$.

Thereupon, equation (5) reduces to

$$P' \cdot q_i(\cdot) - 2\delta_i t_i + (2\delta_i - \gamma\delta_j)D_i' = 0, \quad \forall \, i \in \{1,2\}, \ i \neq j. \tag{6}$$

which defines the reaction function of government i. Solving equations (6) yields the second-stage equilibrium tax rate expressed as $t_i(\cdot) = t_i(\delta_i, \delta_j; w_i, w_j, \gamma)$.

Lemma 2

(i) *The policy choices of each government exhibit the properties of a strategic substitute. In addition, the unique Nash equilibrium in the stage is stable.*

(ii) *The equilibrium tax rate in each country is smaller than the domestic marginal environmental damage (i.e., $t_i < D_i' \ \forall \ i$).*

(iii) *The equilibrium tax rate has the following properties:*

$$\frac{\partial t_i}{\partial \delta_i} > 0, \ \frac{\partial t_i}{\partial \delta_j} < 0, \ \frac{\partial t_i}{\partial w_i} > 0, \ \frac{\partial t_i}{\partial w_j} < 0, \ \frac{\partial t_i}{\partial \gamma} < 0, \quad \forall \, i \in \{1,2\}, \ i \neq j.$$

Proof: See Appendix.

Lemma 2 (ii) implies that each country strategically sets smaller tax rates than the domestic Pigouvian rate. This is due to the following two factors: ecological-dumping[7] and free-riding. The former represents government incentives to relax the domestic environmental taxes for the purpose of shifting profits from the foreign to the domestic firm, and the latter represents them for the purpose of free-riding on foreign country's efforts to reduce the transboundary pollution.

From Lemma 2 (iii), we can see that the equilibrium tax rate is decreasing in own emission efficiency and increasing in rival's. In other words, the improvement of their own environmental technology lowers their own tax and raises the rival's tax. In addition, the tax rates are higher in the country with high wages than in that with low wages. Finally, the equilibrium tax rates in both countries become small if the degree of transboundary pollution is high because a large γ makes the environment more purely public goods (bads) and enlarges the above free-riding factor.

As a result, we obtain the subgame-perfect Nash equilibrium in stages 2 and 3 described as follows:[8]

$$t_i(\cdot) = t_i(\delta_i, \delta_j; \gamma), \quad q_i(\cdot) = q_i(t_i(\cdot), t_j(\cdot), \delta_i, \delta_j),$$

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[7]The term 'ecological-dumping' characterizes situations in which a country uses a too-lax environmental legislation as an instrument of achieving trade-related economic policy goals (Rauscher, 1994).

[8]Obvioully, the equilibrium level of each variable depends on w_i and w_j, but we omit them in the dependent variable because we do not investigate the effects of the changes in w_i.

$$\Pi_i(\cdot) = \Pi_i(q_i(\cdot), q_j(\cdot), t_i(\cdot), \delta_i), \quad R_i(\cdot) = R_i(q_i(\cdot), t_i(\cdot), \delta_i),$$
$$D_i(\cdot) = D_i(q_i(\cdot), q_j(\cdot), \delta_i, \delta_j; \gamma), \quad W_i = \Pi_i(\cdot) + R_i(\cdot) - D_i(\cdot).$$

2.3 Stage 1: Diplomatic negotiations for environmental transfer

Subsequently, we explore the conditions for bilateral agreement on environmental technology transfer between governments. Without loss of generality, we assume that the technology transfer proposal is made by country 1 to 2 (hereafter we call country 1 (2) as a donor (a recipient)). Technology transfer is defined as a marginal improvement of the emission technology of firm 2, i.e. a marginal decrease in δ_2, and is assumed to be unconditional and costless.

It is certain that the agreement cannot be obtained between the recipient and the donor unless the welfare of both countries is enhanced by the transfers. We investigate the conditions under which the agreement can be voluntarily achieved.

The effects of the marginal improvement of the recipient firm on the welfare of each country are

$$\text{Donor}: \ -\frac{\partial W_1}{\partial \delta_2} \ = \ \underbrace{\left(\frac{\partial D_1}{\partial q_2} - \frac{\partial \Pi_1}{\partial q_2}\right)\left(\frac{\partial q_2}{\partial \delta_2} + \frac{\partial q_2}{\partial t_2}\frac{\partial t_2}{\partial \delta_2}\right)}_{(-)}$$
$$+ \underbrace{\left(\frac{\partial D_1}{\partial q_1} - \frac{\partial R_1}{\partial q_1}\right)\left(\frac{\partial q_1}{\partial \delta_2} + \frac{\partial q_1}{\partial t_2}\frac{\partial t_2}{\partial \delta_2}\right)}_{(+)} + \underbrace{\frac{\partial D_1}{\partial \delta_2}}_{(+)}, \quad (7)$$

$$\text{Recipient}: \ -\frac{\partial W_2}{\partial \delta_2} \ = \ \underbrace{\left(\frac{\partial D_2}{\partial q_1} - \frac{\partial \Pi_2}{\partial q_1}\right)\left(\frac{\partial q_1}{\partial \delta_2} + \frac{\partial q_1}{\partial t_1}\frac{\partial t_1}{\partial \delta_2}\right)}_{(+)}$$
$$+ \underbrace{\left(\frac{\partial D_2}{\partial q_2} - \frac{\partial R_2}{\partial q_2}\right)\left(\frac{\partial q_2}{\partial \delta_2} + \frac{\partial q_2}{\partial t_1}\frac{\partial t_1}{\partial \delta_2}\right)}_{(-)} + \underbrace{\frac{\partial D_2}{\partial \delta_2}}_{(+)}. \quad (8)$$

Equation (7) represents the effect of the transfer policy on the donor's welfare, which can be considered as *transfer incentives for the donor*. This can be decomposed into three components. The first under-braced term in (7) represents the negative effect on the donor's welfare through the increases in transboundary pollution and the decreases in the profits of the domestic firm, which are induced by the increases in the output of the recipient firm. This is because the decreases in δ_2 boost the output of the recipient firm by lowering the recipient's tax rate and its emissions.

The second under-braced term in (7) represents the effect on the donor's welfare through the decreases in pollution and tax revenues, which are induced by the decreases in the output of the donor firm. The decreases in δ_2 shrink the output of the donor firm by raising the donor's tax rate and lowering the strategic position of the donor firm against the recipient firm. Since $(\frac{\partial D_1}{\partial q_1} - \frac{\partial R_1}{\partial q_1}) = \delta_1(D_1' - t_1) > 0$ holds in equilibrium (from Lemma 2), the term is positive. The last under-braced term represents the direct effect of the marginal decrease in δ_2 on emission spillovers.

Equation (8) represents the effect of the transfer policy on the recipient's welfare, which can be considered as *adoption incentives for the recipient*. This can also be decomposed into three components. The first under-braced term in (8) represents the positive effect on the recipient's welfare through the decreases in the rival's production, the second under-braced term represents the negative effect through the increases in domestic production, and the third under-braced term represents the direct positive effect.

In order to clearly identify the qualitative properties of two types of incentives, we calculate the explicit forms of equations (7) and (8) by substituting the results of Lemmas 1 and 2 into them. Thus we have

$$\text{Donor}: -\frac{\partial W_1}{\partial \delta_2} = \frac{(\delta_2 \gamma D_1' - P' q_1)(8D_2' + \gamma D_1')}{10P'} + \gamma D_1' q_2 \gtrless 0, \tag{9}$$

$$\text{Recipient}: -\frac{\partial W_2}{\partial \delta_2} = -\frac{\gamma \delta_1 (2\gamma D_1' + D_2')D_2'}{5P'} + \frac{2(\gamma D_1' + 3D_2')}{5}q_2 > 0. \tag{10}$$

From equation (10), we find that the adoption incentives are always positive. However, the sign of the transfer incentives for the donor (9) is ambiguous since the first term in (9) is negative while the second term is positive. If $\gamma = 0$, the second-tem is equal to zero and the equation would reduce to $-4D_2' q_1 / 5 < 0$, which implies that the transfer incentives are necessarily negative for purely domestic pollution. In contrast, if $\gamma = 1$, (9) would reduce to

$$-\frac{\partial W_1}{\partial \delta_2}\bigg|_{\gamma=1} = -\frac{1}{5P'}\left[5D_1'\Big(2\delta_2(D_2' - t_2) - \delta_1 D_2'\Big) - \delta_1(D_1' + 8D_2')(D_1' - t_1)\right]. \tag{11}$$

In a symmetric equilibrium ($D_i' = D'$, $t_i = t$, $\delta_i = \delta \ \forall i \in \{1,2\}$), the above reduces to $\frac{\delta D'(4D'+t)}{5P'}$, which implies that the transfer incentives for the donor are also negative unless $t > -4D'$. However, in the case where t_2 is sufficiently low relative to t_1, the incentives would be positive. Table 1 presents the simulation results in which we specify the inverse demand as $P(Q) = A - q_1 - q_2$. In Case (A), we choose the parameters that lead to $t_1 > 0$ and $t_2 < 0$. In such a case with large policy differentiation, the transfer enhances both countries' welfare for $w_2 < 1.2$. In Case (B), we choose the parameters that lead to $t_i > 0$, $\forall i$. Further, in this case, the transfer benefits both when $w_2 = 1$. From the table, we can confirm that the technology transfer is Pareto-improving if there are strong asymmetries of the wage, the marginal damage, and the tax rate between the countries. Thus, we have the following proposition:

Table 1 goes here.

Proposition 1
A bilateral agreement with respect to the environmental technology transfer cannot be reached between countries that implement similar environmental tax policies except when there is a strong asymmetry between them.

The reason behind the disagreement on the transfer is that the improvement in the recipient firm's emission coefficients of the recipient firm has two negative effects on the donor's welfare:

one is the decreases in the recipient's tax rate and the other is the decreases in the marginal production cost of the rival firm. The former effect induces the donor to raise the tax rate because policy settings are strategic substitutes, and the latter effect leads the donor firm to reduce its output because quantity settings are strategic substitutes as well.[9]

In the next section, in order to clearly demonstrate the importance of the difference in the environmental policies implemented by countries with respect to the welfare results of technology transfers, we will consider a distinctive case in which one country does not levy tax on the domestic firm but another does under non-negative constraint on emission tax rates.

3　Policy Differentiation Considered

In the previous section, we assumed that countries can set a negative rate of emission taxes, that is, emission subsidies. In this section, we exclude the possibilities that countries set a negative environmental tax rate, due to, for example, the constraints of the WTO agreements. We consider the case where one country (country N) levies positive environmental tax but the other (country S) does not, i.e. $t_N > 0$ and $t_S = 0$ hold in the second stage equilibrium. This modification enables us to clearly show the importance of policy differentiation in the technology transfer policies.

From Lemma 2, $t_N > 0$ and $t_S = 0$ may hold in the second stage equilibrium when w_S or D'_S is sufficiently low. In other words, if a particular county has a much smaller wage or environmental awareness than the other, then it sets a zero tax rate. This is the reason we call it as a southern country (country S).

The equilibrium in stage 3 is the same as before. In stage 2, $t_N > 0$ and $t_S = 0$ are obtained when the following (first-order) conditions hold:

$$\text{Country N:} \quad P'q_N - 2\delta_N t_N + (2\delta_N - \gamma\delta_S)D'_N = 0, \tag{12}$$
$$\text{Country S:} \quad P'q_S - 2\delta_S t_S + (2\delta_S - \gamma\delta_N)D'_S < 0.$$

From $t_S = 0$, there is no strategic relationship in setting environmental taxes, and the equilibrium value of t_N is obtained by $t_N(\delta_N, \delta_S)$ from (12).

Lemma 3
The equilibrium tax rate of country N in the second stage has the following properties:

$$\frac{\partial t_N}{\partial \delta_N} = \frac{3D'_N - 2t_N}{2\delta_N} > 0, \quad \frac{\partial t_N}{\partial \delta_S} = -\frac{3\gamma D'_N}{4\delta_N} < 0, \quad \frac{\partial t_N}{\partial \gamma} = -\frac{3\delta_S D'_N}{4\delta_N} < 0.$$

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[9]Alternatively, consider the case where technology transfers can be implemented between firms (not governments) in stage 1. In this situation, the agreement is never reached for free since it holds that

$$-\frac{\partial \Pi_i}{\partial \delta_j} = \underbrace{-\frac{\partial \Pi_i}{\partial q_j}\frac{\partial q_j}{\partial \delta_j}}_{(-)} \underbrace{-\frac{\partial \Pi_i}{\partial q_j}\left(\frac{\partial q_j}{\partial t_i}\frac{\partial t_i}{\partial \delta_j} + \frac{\partial q_j}{\partial t_j}\frac{\partial t_j}{\partial \delta_j}\right) - \frac{\partial \Pi_i}{\partial t_i}\frac{\partial t_i}{\partial \delta_j}}_{(-)} < 0.$$

Proof: See Appendix.

As a result, we obtain the subgame-perfect Nash equilibrium in stages 2 and 3, which is described as follows:

$$t_N = t_N(\delta_N, \delta_S; \gamma), \ t_S = 0, \ q_N = q_N(t_N(\cdot), \delta_N), \ q_S = q_S(t_N(\cdot), \delta_N),$$
$$\Pi_N = \Pi_N(q_N(\cdot), q_S(\cdot), t_N(\cdot), \delta_N), \ \Pi_S = \Pi_S(q_N(\cdot), q_S(\cdot))$$
$$W_N = \Pi_N(\cdot) + R_N(q_N(\cdot), t_N(\cdot), \delta_N) - D_N(q_N(\cdot), q_S(\cdot), \delta_N, \delta_S; \gamma),$$
$$W_S = \Pi_S(\cdot) - D_S(q_N(\cdot), q_S(\cdot), \delta_N, \delta_S; \gamma).$$

Subsequently, we investigate the welfare effects of the environmental technology transfer from countries N to S. The effects of the marginal decrease (improvement) in δ_S (emission technology) on welfare of the donor and recipient countries are obtained as follows:

$$\text{Donor} : \ -\frac{\partial W_N}{\partial \delta_S} = \frac{\partial D_N}{\partial \delta_S} = \gamma D'_N q_S > 0, \tag{13}$$

$$\text{Recipient} : \ -\frac{\partial W_S}{\partial \delta_S} = \underbrace{\left(\frac{\partial D_S}{\partial q_N} - \frac{\partial \Pi_S}{\partial q_N} \right) \left(\frac{\partial q_N}{\partial t_N} \frac{\partial t_N}{\partial \delta_S} \right)}_{(+)} + \underbrace{\frac{\partial D_S}{\partial q_S} \left(\frac{\partial q_S}{\partial t_N} \frac{\partial t_N}{\partial \delta_S} \right)}_{(-)} + \underbrace{\frac{\partial D_S}{\partial \delta_S}}_{(+)}$$

$$= -\frac{\gamma(2\gamma\delta_N - \delta_S)D'_N - 4P'q_S}{4P'} D'_S + \frac{\gamma D'_N}{2} q_S > 0. \tag{14}$$

From (13) and (14), we can see that the transfer incentives for the donor as well as the adoption incentives for the recipient are necessarily positive and are increasing in γ, D'_N, and q_S. The intuitions are as follows. First, the recipient government cannot reduce the tax rates after adopting the transfers because of the assumption of the nonnegative constraint of the environmental tax. Second, adopting more efficient technologies cannot better the strategic position of the recipient firm against the donor firm under market competition with $t_S = 0$. Thus, transferring the environmental technologies would benefit the donor only through the decreases in the transboundary pollution.

Proposition 2
Under the situation where emission subsidies are prohibited, the agreement of the environmental technology transfer can be reached if the transfer is implemented from the country that sets positive environmental taxes to the country that does not.

Notice that although technology transfer from country N to S enhances both countries' welfare, it reduces the profits in country N. This can be confirmed by differentiating Π_N in $-\delta_S$:

$$-\frac{\partial \Pi_N}{\partial \delta_S} = -\left(\frac{\partial \Pi_N}{\partial q_S} \frac{\partial q_S}{\partial t_N} \frac{\partial t_N}{\partial \delta_S} + \frac{\partial \Pi_N}{\partial t_N} \frac{\partial t_N}{\partial \delta_S} \right) = -\frac{\gamma D'_N}{4} q_N < 0.$$

Thus, the policy makers in the donor country should consider an allocation of the gains from transfer or the tax revenues to the domestic firms in order to attract political support for the transfer policy from the firm industries.

4 Product Differentiation Considered

In this section, we incorporate the second type of differentiation, the product differentiation, into the basic model. We consider the homogenous case except for the product qualities of each firm.

The inverse demand function of a world market is defined here as $P_i(q_i, q_j, \theta) \ \forall \ i \in \{1,2\}, i \neq j$, where $\theta \in [0,1]$ represents the degree of product differentiation. The function is assumed to be

$$\frac{\partial P_i}{\partial q_i} \equiv P' < 0, \quad \frac{\partial P_i}{\partial q_j} = \theta P', \quad \frac{\partial P_i}{\partial \theta} = P'_i q_j, \quad \frac{\partial^2 P_i}{\partial q_i^2} = \frac{\partial^2 P_i}{\partial q_i \partial q_j} = 0 \qquad \forall i \in \{1,2\}, i \neq j,$$

where two products are perfectly differentiated when $\theta = 0$ and are perfectly substitutable (homogenous) when $\theta = 1$.[10] Except for the differentiated products, the model structures are similar to the basic model in Section 2.

First, we derive the equilibrium in the third stage. From the first-order conditions for the profit maximization of each firm $i \in \{1,2\}$, we obtain the following lemma.

Lemma 4

The equilibrium output in the third stage has the following properties:

$$\frac{\partial q_i}{\partial t_i} = \frac{2\delta_i}{(4-\theta^2)P'_i} < 0, \quad \frac{\partial q_i}{\partial t_j} = -\frac{\theta \delta_j}{(4-\theta^2)P'_j} > 0,$$

$$\frac{\partial q_i}{\partial \delta_i} = \frac{2t_i}{(4-\theta^2)P'_i} < 0, \quad \frac{\partial q_i}{\partial \delta_j} = -\frac{\theta t_j}{(4-\theta^2)P'_j} > 0, \quad \frac{\partial q_i}{\partial \theta} = -\frac{2q_j - \theta q_i}{(4-\theta^2)}.$$

Proof: See Appendix.

Notice that the values of $\partial q_i/\partial t_j$ and $\partial q_i/\partial \delta_j$ become small if θ closes to zero, which implies that product differentiation weakens the market interactions between the firms.

Subsequently, we solve the second-stage equilibrium. The first-order conditions for the welfare maximization of the governments are obtained as follows:

$$\theta^2 P'_i q_i - 2\delta_i t_i + (2\delta_i - \gamma\theta\delta_j)D'_i = 0 \qquad \forall i \in \{1,2\}, i \neq j, \tag{15}$$

which is the reaction function of government i. Solving (15) yields the equilibrium tax rates in country i described by $\tilde{t}_i(\delta_i, \delta_j, \gamma, \theta)$.

Lemma 5

$\tilde{t}_i = D'_i$ if $\theta = 0$, and $\tilde{t}_i < D'_i$ otherwise.

Proof: This can be easily shown from (15) by applying the proof of Lemma 2 (ii).

The lemma states that if the products are perfectly differentiated, then the equilibrium tax rates set by each government are equal to the domestic marginal environmental damage;

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[10]For example, the linear inverse demand function such as $P_i = A - b(q_i + \theta q_j)$ has the same properties that we assume.

otherwise, the equilibrium tax rates are less than the domestic marginal environmental damage. In other words, the optimal environmental tax levied on the domestic firm, which is a monopolist in the world market, coincides with the Pigouvian tax rate, even if there are negative pollution spillovers. The result of $\theta = 0$ here is consistent with the results of Rauscher (1997).[11]

Lemma 6

In a symmetric equilibrium, the equilibrium tax rate in the second stage has the following properties:

$$\frac{\partial \tilde{t}_i}{\partial \delta_i} = \frac{\Omega D' - \Phi t}{\Phi \delta} > 0, \quad \frac{\partial \tilde{t}_i}{\partial \delta_j} = -\frac{2\theta[2\gamma(2-\theta^2)+\theta^2]D'}{\Phi\delta} < 0,$$

$$\frac{\partial \tilde{t}_i}{\partial \gamma} = -\frac{\theta(2+\theta)D'}{4+2\theta-\theta^2} < 0, \quad \frac{\partial \tilde{t}_i}{\partial \theta} = -\frac{\gamma\delta(2+\theta)D' - \theta(4+\theta)P'q}{\delta(4+2\theta-\theta^2)} < 0,$$

where $\Phi = (\theta^2 - 2\theta - 4)(\theta^2 + 2\theta - 4) > 0$ and $\Omega = (16 + \gamma\theta^4 - 8\theta^2) > \Phi > 0$.

Proof See Appendix.

In the lemma, it holds that $\partial \tilde{t}_i / \partial \theta < 0$, which implies that the equilibrium tax rate becomes smaller as the products are more homogenous. As θ increases, the competition in the world market becomes severe, and the profit-shifting effects of environmental taxes also increase. Thus, each government sets a lower tax rate as θ increases, which can be considered as a type of ecological-dumping.

Each variable in the subgame-perfect Nash equilibrium in stages 2 and 3 is obtained as follows:

$$\tilde{t}_i(\cdot) = \tilde{t}_i(\delta_i, \delta_j, \gamma, \theta), \quad \tilde{q}_i(\cdot) = \tilde{q}_i(\tilde{t}_i(\cdot), \tilde{t}_j(\cdot), \delta_i, \delta_j, \theta),$$
$$\widetilde{\Pi}_i(\cdot) = \widetilde{\Pi}_i(\tilde{q}_i(\cdot), \tilde{q}_j(\cdot), \tilde{t}_i(\cdot), \delta_i), \quad \widetilde{W}_i = \widetilde{\Pi}_i(\cdot) + \delta_i\tilde{q}_i(\cdot)\tilde{t}_i(\cdot) - D_i(\delta_i\tilde{q}_i + \gamma\delta_j\tilde{q}_j(\cdot))$$

Prior to the exploration of the welfare effects of technology transfers, we mention the effect of product differentiation on the equilibrium outputs and on pollution.

Lemma 7

The equilibrium output of each firm $\tilde{q}_i$ has the following properties:

$$\frac{\partial \tilde{q}_i}{\partial \theta} \gtrless 0 \iff -P' \lessgtr \frac{\gamma\delta D'}{2(1-\theta)\tilde{q}}.$$

Proof: Differentiating $\tilde{q}_i$ in θ and evaluating them in a symmetric equilibrium, we get

$$\frac{\partial \tilde{q}_i}{\partial \theta} = \frac{\partial \tilde{q}_i}{\partial \tilde{t}_i}\frac{\partial \tilde{t}_i}{\partial \theta} + \frac{\partial \tilde{q}_i}{\partial \tilde{t}_j}\frac{\partial \tilde{t}_j}{\partial \theta} + \frac{\partial \tilde{q}_i}{\partial \theta} = -\frac{\gamma\delta D' + 2(1-\theta)P'\tilde{q}}{(4+2\theta-\theta^2)P'}.$$

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[11]In Rauscher (1997), constructing the model of monopolistic behavior, he showed that the optimal environmental policy vis-à-vis a domestic firm, which is a monopolist in the foreign market, is to use a Pigouvian emission tax (Proposition 6.2 in Rauscher (1997)).

Figure 1 goes here.

In the standard theory of Cournot oligopoly with product differentiation, the individual and aggregate outputs decline when the products are less differentiated.[12] In fact, in our model, Lemma 5 indicates that $\partial q_i / \partial \theta < 0$ holds in a symmetric equilibrium if we ignore the effects of θ on the tax rate set by both governments. However, since an increase in θ lowers the tax rates (from Lemma 6), it is possible for $\partial \tilde{q}_i / \partial \theta > 0$ to hold. Figure 1 illustrates the results.[13] In the region below the $\partial \tilde{q}_i / \partial \theta = 0$ line, the outputs, and hence, pollution increases if each firm is more successful in differentiating the products from the other firm's. In other words, a movement towards product differentiation by firms (a decrease in θ) is detrimental for the environment in the concerned region. On the other hand, in the region above the $\partial \tilde{q}_i / \partial \theta = 0$ line, a movement towards product differentiation reduces the output and pollution and, hence, is desirable for the environment.

Finally, we investigate the welfare effects of a technology transfer. Differentiating $\widetilde{W}_1$ (the welfare of the donor) and $\widetilde{W}_2$ (the welfare of the recipient) in $-\delta_2$ and evaluating them in a symmetric equilibrium, we obtain

$$\text{Donor}: \ -\frac{\partial \widetilde{W}_1}{\partial \delta_2} = \frac{\Omega(\gamma \delta D' - \theta P' \tilde{q})}{2 \Phi P'} D' + \gamma D' \tilde{q} \gtrless 0 \tag{16}$$

$$\text{Recipient}: \ -\frac{\partial \widetilde{W}_2}{\partial \delta_2} = -\frac{\theta(2\gamma(2-\theta^2)+\theta^2)\gamma \delta D'^2}{\Phi P'} + \frac{2(2-\theta^2)\{4-(1-\gamma)\theta^2\}D'}{\Phi} \tilde{q} > 0. \tag{17}$$

We can see, from (16) and (17), that the adoption incentives for the recipient are necessarily positive, while the transfer incentives for the donor are ambiguous. Clearly, the sign of (16) would be negative if $\gamma = 0$. If $\theta = 0$, then by using Lemma 6, equation (16) can be reduced to

$$-\frac{\partial \widetilde{W}_1}{\partial \delta_2}\bigg|_{\theta=0} = -\frac{\gamma D'}{P'}\left\{\frac{P^M}{\epsilon} - \frac{\delta \tilde{t}}{2}\right\} \gtrless 0 \quad \Leftrightarrow \quad \epsilon \lessgtr \frac{2P^M}{\delta \tilde{t}},$$

where $\epsilon \equiv -\frac{P}{P'q} \in [0, \infty]$ is the price elasticity of demand and P^M is the monopoly price.

Proposition 3
When the products are perfectly differentiated, the technology transfers are Pareto-improving for $\epsilon < \frac{2P^M}{\delta \tilde{t}}$. The transfers are more likely to be Pareto-improving when γ is large and θ and D' are small.

Since the price elasticity of a dirty good is generally small and the values of $\delta \tilde{t}$ (the tax payments per unit of output) are much smaller than P^M, $\epsilon < \frac{2P^M}{\delta \tilde{t}}$ is not a special case.

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[12]See, for example, Shy (1995).
[13]In order to illustrate Figure 1, we specify the inverse demand as $P_i = A - q_i - \theta q_j$ and use the parameters of $A = 20$, $w_i = 0$, $\delta_i = 1$, $D'_i = 8$, $\forall i$.

Figure 2 illustrates the $-\partial \widetilde{W}_i / \partial \delta_j = 0$ line.[14] The transfer incentives for the donor are positive (negative) if θ and γ are in the area above (below) the line. Further, form the figure, we can confirm that product differentiation may encourage the international transfer of environmental technologies.[15]

Figure 2 goes here.

The intuition behind Proposition 3 is as follows. Firstly, when γ is large, the decreases in the emissions of the recipient firm become more beneficial to the donor. Secondly, when θ is small, the cost reductions of the recipient firm have a smaller effect on the profits of the donor firm. Finally, when D' is small, the tax rates in both countries are also small, which means that the cost reductions of the recipient firm are also small. In that case, the transfer does not undermine the strategic position of the donor firm in the market to a great extent. Consequently, a larger γ and smaller θ and D' tend to raise the transfer incentives for the donor.

5   Concluding Remarks

This paper has investigated the welfare effects of environmental technology transfers in open economies with international oligopoly and transboundary pollution. We have shown that when there are very little differences in the qualities produced or the policies implemented between the donor and the recipient, the transfer incentives for the donor government would be negative since the transfer may induce the recipient not only to relax its environmental policies due to strategic policy relationships but also to increase the outputs due to the strategic market relationships. Such a dismal result with respect to technology transfers changed qualitatively when we take into consideration the differentiation regarding the policies and product qualities. With respect to the policy differences, we have considered the case in which the donor county levies positive environmental taxes on the domestic firm and the recipient country does not under a non-negative constraint on emission tax rates. In this case, the technology transfer would be Pareto-improving despite the existence of international oligopoly. This is because the recipient government cannot relax its environmental policy any further; that is, the strategic policy relationships are absent. As for the product differentiations, we have shown that when the products are highly differentiated, technology transfer would also be Pareto-improving despite the negative reactions by the recipient government. This is because the product differentiation

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[14]The figure is obtained by specifying the inverse demand as $P_i = A - q_i - \theta q_2$ and the parameters as $A = 20$, $w_i = 0$, $\delta_i = 1$ and $D'_i = 8$, $\forall\, i$.

[15]As in the previous policy differentiation model, the profits of the donor firm here are reduced by the diplomatic policy of the technology transfer since

$$-\frac{\partial \Pi_i}{\partial \delta_j} = -\frac{2\theta D' q}{\Phi}\Big[4 + 4\gamma - \gamma\theta^2\Big] < 0.$$

Thus, the policy makers in the donor country should allocate the gains from the transfer to the domestic firms in order to gain their political support.

reduces the strategic market relationships between firms. In other words, the two asymmetries in policies and products weaken the policy and market relationships between nations and, hence, encourage the international transfers of environmental technologies.

It is interesting to draw a connection between our results and those of Barrett (2001). In his seminal work, Barrett (2001) shows that the strong asymmetry among countries plays a key role in the enlargement of a self-enforcing international environmental agreement. Although his model structure and subject of investigation are essentially different from ours, their implications are similar with regard to the importance of asymmetry among countries for the encouragement of environmental cooperation.

There are a few extensions of the model that may be worth exploring. One extension would be to consider the existence of the domestic market. Given the imperfect competition by firms, policy makers would set much laxer environmental policies for fear of reducing domestic consumer surplus. In this case, the welfare results of environmental technology transfer may change. Another conceivable extension would be to consider another functional form of environmental damages. Indeed, our results may depend on the fact that the policy choices by governments are strategic substitutes, which comes from our assumption of the linearity of the environmental damage function. If we assume a strongly convex damage function, then the tax choices by governments would be strategic complements. Moreover, in this case, the results of the technology transfer may change. These matters await future investigation.

Appendix

Proof of Lemma 1

Total differentiation of (4) yields

$$\begin{pmatrix} 2P' + q_i P'' & P' + q_i P'' \\ P' + q_j P'' & 2P' + q_j P'' \end{pmatrix} \begin{pmatrix} dq_i \\ dq_j \end{pmatrix} = \begin{pmatrix} t_i \\ 0 \end{pmatrix} d\delta_i + \begin{pmatrix} \delta_i \\ 0 \end{pmatrix} dt_i + \begin{pmatrix} 1 \\ 0 \end{pmatrix} dw_i$$

where $\Delta = \begin{pmatrix} 2P' + q_i P'' & P' + q_i P'' \\ P' + q_j P'' & 2P' + q_j P'' \end{pmatrix} = 3(P')^2 + Q\,P'P'' > 0$. From the above, we obtain the following comparative static results, for $i, j = 1, 2, i \neq j$.

$$\frac{\partial q_i}{\partial t_i} = (2P' + q_j P'')\delta_i/\Delta < 0, \qquad \frac{\partial q_i}{\partial t_j} = -(P' + q_i P'')\delta_j/\Delta > 0,$$

$$\frac{\partial q_i}{\partial \delta_i} = (2P' + q_j P'')t_i/\Delta < 0, \qquad \frac{\partial q_i}{\partial \delta_j} = -(P' + q_i P'')t_j/\Delta > 0,$$

$$\frac{\partial q_i}{\partial w_i} = (2P' + q_j P'')/\Delta < 0, \qquad \frac{\partial q_i}{\partial w_j} = -(P' + q_i P'')/\Delta > 0.$$

Proof of Lemma 2

(i) Suppose (t_i^*, t_j^*) is the equilibrium tax rate and $t_i^* = D_i' + \epsilon$ holds for a nonnegative ϵ. Then, it holds that

$$P' \cdot q_i(\cdot) - 2\delta_i t_i^* + (2\delta_i - \gamma\delta_j)D_i' = P' \cdot q_i(\cdot) - (2\delta_i\epsilon + \gamma\delta_j D_i') < 0,$$

since $q_i(\cdot)$ is nonnegative for any value of (t_i^*, t_j^*). This contradicts with (6). Thus, ϵ must be negative, which means $t_i^* < D_i'$.

(ii) From (6), we obtain the slope of the reaction function as

$$\left. \frac{dt_i}{dt_j} \right|_{foc} = -\frac{\partial^2 W_i/\partial t_i \partial t_j}{\partial^2 W_i/\partial t_i^2} = -\frac{\delta_j}{4\delta_i} < 0,$$

which means that the policy choices in the second stage exhibit a strategic substitute. In addition, the stability condition of the equilibrium

$$\left| \frac{\partial^2 W_i}{\partial t_i^2} \right| > \left| \frac{\partial^2 W_i}{\partial t_i \partial t_j} \right|$$

is satisfied because $\frac{4\delta_i}{3} > \frac{\delta_j}{3}$ (the inequality sign comes from Assumption 1).

(iii) With using the results of Lemma 1, the total differentiation of (6) yields

$$\begin{pmatrix} -\frac{4}{3}\delta_i & -\frac{1}{3}\delta_j \\ -\frac{1}{3}\delta_i & -\frac{4}{3}\delta_j \end{pmatrix} \begin{pmatrix} dt_i \\ dt_j \end{pmatrix} = \begin{pmatrix} \frac{4}{3}t_i - 2D_i' \\ \frac{1}{3}t_i + \gamma D_j' \end{pmatrix} d\delta_i + \begin{pmatrix} -\frac{2}{3} \\ \frac{1}{3} \end{pmatrix} dw_i$$

where $\bar{\Delta} = \begin{pmatrix} -\frac{4}{3}\delta_i & -\frac{1}{3}\delta_j \\ -\frac{1}{3}\delta_i & -\frac{4}{3}\delta_j \end{pmatrix} = \frac{5}{3}\delta_i\delta_j > 0$. From the above, we obtain the following comparative static results, for $i, j = 1, 2$, $i \neq j$.

$$\frac{\partial t_i}{\partial \delta_i} = -\frac{5t_i - 8D_i' - \gamma D_j}{5\delta_i} > 0, \quad \frac{\partial t_i}{\partial \delta_j} = -\frac{2(2\gamma D_i' + D_j')}{5\delta_i} < 0,$$

$$\frac{\partial t_i}{\partial w_i} = \frac{3}{5\delta_i} > 0, \quad \frac{\partial t_i}{\partial w_j} = -\frac{2}{5\delta_i} < 0$$

where $\partial t_i/\partial \delta_i > 0$ comes from $t_i < D_i'$ of Lemma 2 (i).

Proof of Lemma 3

The total differentiation of (12) yields

$$\left[P'\frac{\partial q_N}{\partial t_N} - 2\delta_N \right]dt_N + \left[P'\frac{\partial q_N}{\partial \delta_N} - 2t_N + 2D_N' \right]d\delta_N + \left[P'\frac{\partial q_N}{\partial \delta_S} - \gamma D_N' \right]d\delta_S + \left[P'\frac{\partial q_N}{\partial \gamma} - \delta_S D_N' \right]d\gamma = 0.$$

With using Lemma 1 and $t_S = 0$, we obtain the comparative static results as

$$\frac{\partial t_N}{\partial \delta_N} = \frac{3D_N' - 2t_N}{2\delta_N} > 0, \quad \frac{\partial t_N}{\partial \delta_S} = -\frac{3\gamma D_N'}{4\delta_N} < 0, \quad \frac{\partial t_N}{\partial \gamma} = -\frac{3\delta_S D_N'}{4\delta_N} < 0.$$

Proof of Lemma 4

The first-order conditions for profit maximization of both firms are

$$P_i + P_i' q_i - w_i - \delta_i t_i = 0 \qquad \forall i \in \{1, 2\}.$$

Thus, the total differentiation of the above yields

$$\begin{pmatrix} 2P_i' & \theta P_i' \\ \theta P_j' & 2P_j' \end{pmatrix} \begin{pmatrix} dq_i \\ \theta P_j' \end{pmatrix} = \begin{pmatrix} t_i \\ 0 \end{pmatrix} d\delta_i + \begin{pmatrix} \delta_i \\ 0 \end{pmatrix} dt_i + \begin{pmatrix} P_i' q_j \\ P_j' q_i \end{pmatrix} d\theta$$

where determinant is $\begin{vmatrix} 2P_i' & \theta P_i' \\ \theta P_j' & 2P_j' \end{vmatrix} = (4 - \theta^2) P_i' P_j' > 0$. Then, we obtain the comparative static results as in the lemma.

Proof of Lemma 6

The total differentiation of (15) yields

$$\begin{pmatrix} -\frac{4\delta_i(2-\theta^2)}{4-\theta^2} & -\frac{\theta^3 \delta_j P_i'}{(4-\theta^2)P_j'} \\ -\frac{\theta^3 \delta_i P_j'}{(4-\theta^2)P_i'} & -\frac{4\delta_j(2-\theta^2)}{4-\theta^2} \end{pmatrix} \begin{pmatrix} dt_i \\ dt_j \end{pmatrix} = \begin{pmatrix} \frac{4t_i(2-\theta^2)}{4-\theta^2} - 2D_i' \\ \frac{\theta^3 t_j P_i'}{(4-\theta^2)P_j'} + \gamma D_i' \end{pmatrix} d\delta_i + \begin{pmatrix} \delta_j D_i' \\ \delta_i D_j' \end{pmatrix} d\gamma$$

$$+ \begin{pmatrix} -\frac{\theta(q_i(8-\theta^2)-2\theta q_j)P_i'}{4-\theta^2} + \gamma \delta_j D_i' \\ -\frac{\theta(q_j(8-\theta^2)-2\theta q_i)P_j'}{4-\theta^2} + \gamma \delta_i D_j' \end{pmatrix} d\theta$$

where the determinant, by evaluating it in a symmetric equilibrium, is

$$\begin{vmatrix} -\frac{4\delta_i(2-\theta^2)}{4-\theta^2} & -\frac{\theta^3 \delta_j P_i'}{(4-\theta^2)P_j'} \\ -\frac{\theta^3 \delta_i P_j'}{(4-\theta^2)P_i'} & -\frac{4\delta_j(2-\theta^2)}{4-\theta^2} \end{vmatrix} = \frac{\delta^2 \Phi}{4 - \theta^2} > 0.$$

Lemma 6 is obtained by the comparative statics of the above.

Acknowledgments

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Table 1: The transfer incentives for the donor when $\gamma = 1$

inverse demand : $P(Q) = A - q_1 - q_2$

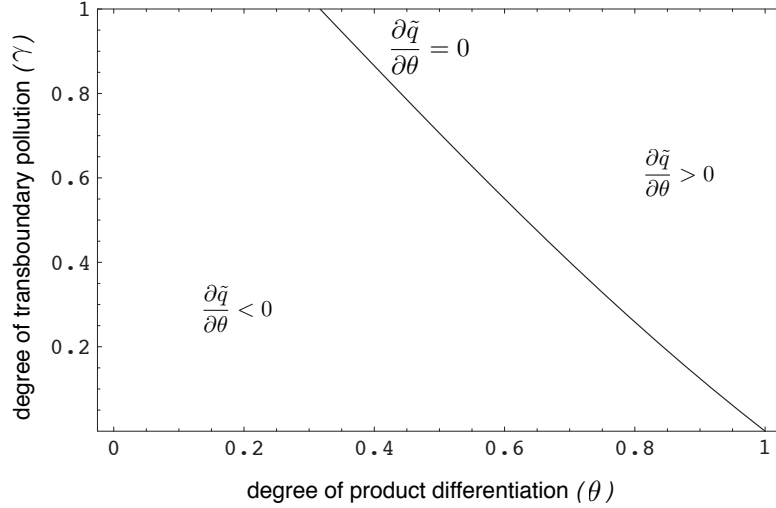| Case (A)	Case (B)
$A = 20,\ \gamma = 1,\ D'_1 = 12, D'_2 = 5$	$A = 20,\ \gamma = 1,\ D'_1 = 15, D'_2 = 8.7$
$\delta_1 = 1,\ \delta_2 = 1.2,\ w_1 = 2$	$\delta_1 = 1,\ \delta_2 = 1.05,\ w_1 = 3$
(i) $w_2 = 0.8 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = 7.424 > 0$	(i) $w_2 = 0.8 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = 5.035 > 0$
$q_1 = 3.28,\ q_2 = 8.28$	$q_1 = 0.318,\ q_2 = 9.4$
$t_1 = 3.16,\ t_2 = -0.53$	$t_1 = 6.97,\ t_2 = 0.08$
(ii) $w_2 = 1.0 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = 3.712 > 0$	(ii) $w_2 = 1.0 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = 0.08 > 0$
$q_1 = 3.44,\ q_2 = 8.04$	$q_1 = 0.48,\ q_2 = 9.16$
$t_1 = 3.08,\ t_2 = -0.43$	$t_1 = 6.89,\ t_2 = 0.2$
(iii) $w_2 = 1.2 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = 0$	(iii) $w_2 = 1.2 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = -4.872 < 0$
$q_1 = 3.6,\ q_2 = 7.8$	$q_1 = 0.64,\ q_2 = 8.92$
$t_1 = 3,\ t_2 = -0.33$	$t_1 = 6.81,\ t_2 = 0.31$
(iv) $w_2 = 1.4 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = -3.712 < 0$	(iv) $w_2 = 1.4 \Leftrightarrow -\dfrac{\partial W_1}{\partial \delta_2} = -9.826 < 0$
$q_1 = 3.76,\ q_2 = 7.56$	$q_1 = 0.8,\ q_2 = 8.68$
$t_1 = 3.16,\ t_2 = -0.23$	$t_1 = 6.73,\ t_2 = 0.42$

Figure 1: Product differentiation and outputs
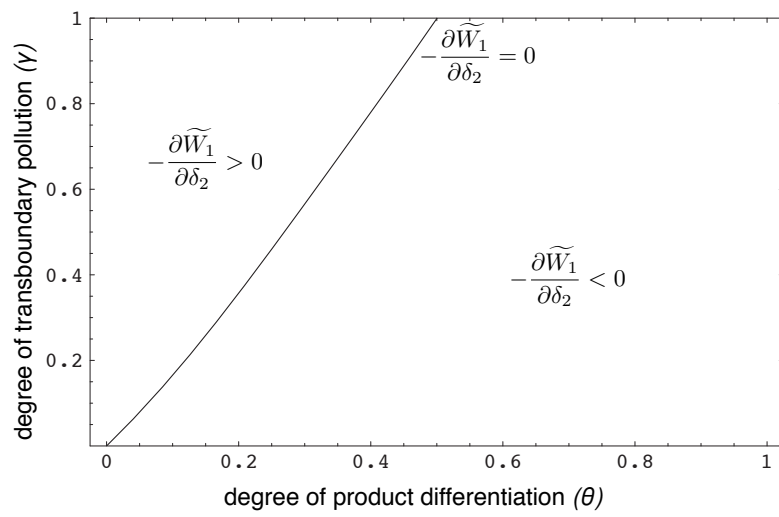
Figure 2: The transfer incentives for the donor