Technology Transfer and the South's Participation in an International Environmental Agreement

Larry D. Qiu*
Hong Kong University of Science and Technology

Zhihao Yu**
Carleton University

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Abstract

We develop a North-South model of international trade and transboundary pollution to analyze the relationship between environmental technology transfer and the South's incentive to join an international environmental agreement (IEA). We find necessary and sufficient conditions under which technology transfer will increase the South's incentive to join the IEA. We also find necessary and sufficient conditions under which the South's participation in the IEA will increase the market incentive for technology transfer. Results have clear policy implications for (i) the sequence of technology transfer and the South's IEA membership and (ii) the legitimacy of the South's subsidies for technology transfer.

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* Correspondence to: Larry D. Qiu, Department of Economics, Hong Kong University of Science and Technology, Kowloon, Hong Kong. Tel number: +(852)2358-7628, Fax number: +(852)2358-2084, Email: larryqiu@ust.hk, Homepage: http://www.bm.ust.hk/~larryqiu.
** Email: zhihao_yu@carleton.ca, Homepage: http://www.carleton.ca/~zyu.

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1. Introduction

With awareness of environmental issues increasing across the globe, we have witnessed the emergence of many international environmental agreements (IEAs) over the past two decades. However, the nonsignatories of many IEAs often include some large developing countries (such as China and India). So far, over 20 IEAs have included trade measures to induce nonsignatories to sign the agreements.[1] Discriminatory trade-restricting measures, however, are neither consistent with the most-favored-nation principle of the World Trade Organization (WTO) nor are they effective.[2] Instead, a view is commonly shared that nonsignatory countries, which are most likely developing countries, may not be able to afford to raise their environmental standards given their existing technologies. Accordingly, it is often recommended that positive measures and incentives, such as financial assistance and environmental technology transfer, should be used because such measures are more efficient and effective than punitive measures.

In this paper, we develop a North-South model of international trade and transboundary pollution to analyze formally the relationship between environmental technology transfer and the South's (a nonsignatory country) incentive to join an *existing* IEA (formed by the North). Two questions are particularly interesting. First, will technology transfer induce the South to join the IEA? Second, will the South's participation in the IEA increase the market incentives for technology transfer? We use a trade model with imperfect competition to highlight the trade effects of both national and international environmental policy since it is the key issue that fuels the discussion about market access and competitiveness (see Bhagwati and Hudec, 1996).[3] To join an IEA, the South has to reduce its level of pollution emissions, but in return it receives financial transfers from the North as compensation.

Contrary to the common perception, we first show that the transfer of environmental technology does not necessarily increase (rather, it could even reduce) the South's incentive to join

[1]For example, the Basel Convention bans the trade in hazardous wastes with nonsignatories. The Montreal Protocol also bans trade in ozone-depleting substances and products between signatories and nonsignatories.

[2]See Hudec (1996), WTO (1996) and UNE and IISD (2000).

[3]Other approaches based on general equilibrium trade models can be found in, for example, Copeland and Taylor (1994, 1995). Also, we do not consider the case of relocation of polluting firms from the North to the South, which belongs to the literature on the pollution haven hypothesis (see recent work by Eskeland and Harrison, 2003, among many others).

the IEA. There are two reasons for this. On the one hand, with cleaner environmental technology due to technology transfer, the negative effect of a tighter environmental policy on the South's welfare becomes smaller. This raises the South's incentive to join the agreement. On the other hand, however, the South's optimal emission quota after technology transfer could be larger than before. Because of this, the IEA membership requires that the South depart more from its optimal policy level in the case of technology transfer than in the case of no technology transfer. Hence, the South is more reluctant to join the IEA after receiving the better technology. The South's overall incentive depends on the relative importance of these two effects. An implication of this result is that the assisted environmental technology transfer by the IEA member countries should be given before a developing country becomes a signatory of the IEA if technology transfer raises the participation incentive, but it should be given after the country commits to joining the IEA if the technology transfer reduces the participation incentive.

Second, we show that the South's IEA membership may reduce or increase market incentives for technology transfer. Participation in the IEA is the Southern government's decision, but technology transfer involves decisions by firms in both the North and the South. Because of financial compensation, the Southern government may be willing to join the IEA, but the South's inclusion in the IEA means a change of emission quotas, which in turn affects profits from technology transfer. Based on this finding, we can draw the following policy implication: when IEA reduces the incentive for technology transfer, financial transfer, at least in part, should be provided to assist firms in environmental technology transfer or the South should be allowed to subsidize environmental technology transfer.[4]

The literature on the theory of IEAs has mainly focused on the *formation* of IEAs.[5] It has been concluded that *carrots* and *sticks* (e.g., financial assistance and technology transfers as carrots and sanctions as sticks) are needed to induce countries to become signatories of IEAs and to stabilize IEAs (see Barrett, 1997a & b). The use of trade sanctions is based on the idea of an "issue-linkage" to enforce IEAs and that of monetary transfers is based on the principle of "gainers compensate losers". Technology transfers are also considered to be vital, especially for developing countries, because these countries simply may not have access to the

[4]In reality, financial transfers are also used for other purposes, for example, environmental cleaning and pollution abatement (e.g., Hatzipanayotou, Lahiri, and Michael, 2002).

[5]For example, see Heal (1993), among many others.

necessary technology on favorable terms (Charnovitz, 1993; WTO, 1996). This focuses on how to induce a large emerging economy to join an *existing* IEA. To our knowledge, our study is the first to provide a formal analysis of how environmental technology transfer affects developing countries' incentives to join IEAs and how their participation in IEAs affects market incentives for environmental technology transfer.

Pollution quotas are commonly used in IEAs. Accordingly, we focus on pollution quotas as a policy instrument in this paper. Furthermore, to focus on the trade effects (market access and competitiveness) of both national and international environmental policy, we use a model of imperfect competition in the product market. Therefore, similar to the literature on strategic environmental policies (Barrett, 1994; Kennedy, 1994; Conrad, 1996; and Ulph, 1996), environmental policies in this model have the same effects as the more familiar strategic trade policies. However, none of these studies deals with environmental technology transfers and IEA-related issues.

The rest of this paper is organized as follows. Section 2 develops the model in the absence of an IEA. Section 3 focuses on the relationship between technology transfer and the South's incentive to join an IEA. Section 4 discusses pollution taxes and abatement technologies. Section 5 draws concludes. Proof of the propositions are offered in the Appendix.

2. The Model in the Absence of an IEA

To capture the issues of international competitiveness and transboundary pollution, we follow the literature on strategic environmental policy and use the following setup of an imperfectly competitive market structure.[6] There are two countries, called the North (representing a developed country) and the South (representing a large developing country). We assume that there is only one firm in each country: we call the firm located in the North the N-firm and that in the South the S-firm. These firms produce an homogenous product. Production of this product emits pollution. However, the N-firm has cleaner technology than the S-firm in the sense that the pollution content (i.e., the amount of pollutant generated when producing one unit of output) of the N-firm, denoted e_n, is lower than that of the S-firm, denoted e_s, i.e., $e_n < e_s$. The

[6] E.g., see Barrett (1994), Kennedy (1994), and Ulph (1996).

firms are otherwise identical. The N-firm could license its technology to the S-firm, and if it does, the S-firm's pollution content will be reduced to e_n.[7] The Northern government imposes an emissions quota, denoted E_n, on total pollution generated by the N-firm. The corresponding quota imposed by the Southern government is assumed to be E_s.

Following the literature, we use the simplest market structure to capture the issue of competitiveness of a national industry by assuming that the N-firm and S-firm compete in a 'third market' (i.e., the international, rather then their domestic, market). Therefore, the consumer interests in this market will not be taken into account when each government makes its policy decisions. Assume linear demand, $p = 1 - (q_n + q_s)$, where q_i $(i = n,\ s)$ is the output of the i-firm. For simplicity, assume that the firms have constant marginal cost of production and, without loss of generality, assume this cost to be zero. The firms compete on quantity (i.e., in Cournot fashion).

As illustrated in Figure 1, the structure of the game in the absence of an IEA is as follows. The first stage of the game is the technology transfer (TT) decision, where the N-firm makes its licensing decision and both firms negotiate a (lump-sum) licensing fee. The second is the policy stage, in which the policy outcome is the non-cooperative emissions quotas set by the two governments. The third is the production stage, in which the outcome is the non-cooperative output by the two firms in the product market. In the rest of this section, we will derive and analyze the subgame perfect Nash equilibrium (SPNE) for the game in the absence of an IEA.

<Fig. 1 about here>

Similar to Ulph (1996), we assume that the firms move first regarding the decision of technology transfer and the governments move in the second stage to determine their policies (and then the firms move in the third stage in product competition). A justification for putting the technology transfer decision in the first stage of the game is that once the firms have transferred the technology, the decision cannot be reversed. We will also consider a game with a reversed sequence of moves in Section 3.

[7]Environmental technology may also be possessed by a third party (a firm that does not produce the product). But most production-related know-how and patents are owned by the firms that produce the product. Therefore, we adopt the approach that the technology is possessed by the N-firm (which also simplifies the model). Also, it has been argued that prior to technology transfer, the N-firm must spend some effort/money, c, to make the technology suitable for the S-firm. We included this sunk cost in an earlier version of this paper and found no qualitative changes to any of the results.

2.1. The subgame without technology transfer

■ *Production stage.* We first focus on the left panel of the game tree in Figure 1. Given any emissions quotas, $E = \{E_n, E_s\}$, in the second stage, each firm's profit function is given as $\pi_i = pq_i$. The firms choose outputs to maximize their profits subject to policy constraints, $e_i q_i \leq E_i$. When $Q_i \equiv E_i/e_i$, the constraints become $q_i \leq Q_i$. Since e_i are exogenously given, we can also call Q_i the governments' quota policies, for convenience.

Suppose the governments impose no (emissions) quotas. Then, we have a usual Cournot game. As shown in Figure 2, the N-firm's reaction curve is AB ($q_n = (1 - q_s)/2$) and the S-firm's reaction curve is CD ($q_s = (1 - q_n)/2$). The equilibrium is at point O, $(\frac{1}{3}, \frac{1}{3})$. Now with the quotas $Q = \{Q_n, Q_s\}$ in the second stage, there are four possible outcomes: *case 1*, where $Q_n \geq \frac{1}{3}$ and $Q_s \geq \frac{1}{3}$; *case 2*, where $Q_n < \frac{1}{3}$ and $Q_s < \frac{1}{3}$; *case 3*, where $Q_n < \frac{1}{3}$ and $Q_s \geq \frac{1}{3}$; and *case 4*, where $Q_n \geq \frac{1}{3}$ and $Q_s < \frac{1}{3}$. The N-firm's reaction curve is given by $q_n = \min\{(1 - q_s)/2, Q_n\}$ and the S-firm's reaction curve is given by $q_s = \min\{(1 - q_n)/2, Q_s\}$. Figure 2 shows case 2 with A_2B_2B as the N-firm's reaction curve, CC_2D_2 as the S-firm's reaction curve, and equilibrium at O_2 ($q_n = Q_n$, $q_s = Q_s$). It is clear that O is the equilibrium for case 1. Let q_i^0 and π_i^0 denote the third-stage equilibrium in the absence of technology transfer.

<Fig. 2 about here>

■ *Policy stage.* A country's welfare includes its firm's profit and the pollution "damage" to its population:

$$W_i^0 = \pi_i^0 - \beta_i(q_i^0 e_i + q_j^0 e_j), \tag{1}$$

where $\beta_i \geq 0$ captures the seriousness of country i's concern about pollution. Assume $\beta_n > \beta_s > 0$.[8] Note that, to simplify expressions, we assume complete transborder pollution. The main results of the paper hold for partial transborder pollution.

Each government chooses its quota level to maximize its country's welfare. In the Appendix, Section (i), we derive each government's best response to another government's policy. The two policy reaction curves are depicted in Figure 3 under the following assumption:

$$\textbf{(A.1)}: \qquad 2e_n \leq e_s \quad \text{and} \quad \beta_s \leq \frac{1}{3(2e_s - e_n)}.$$

[8] Many factors may give rise to this assumption, for example, that the North has higher income than the South, or that people in the North have stronger environmental awareness than have those in the South.

This assumption gives us a reasonable focus: Northern technology is much cleaner than Southern technology, which emphasizes the importance of technology transfer, and the Southern government does not pay sufficient attention to pollution, which emphasizes the importance of bringing the South into an IEA.

<Fig. 3 about here>

Two critical points on the reaction curves are uniquely determined: $r_n^0 \in (\frac{1}{3}, \frac{1+\beta_s e_s}{3})$ and $r_s^0 \in (\frac{1}{3}, \frac{1+\beta_n e_n}{3})$. The equilibrium policies are determined by the intersection of the two reaction curves, R_n^0 and R_s^0. Let us focus on the case where the two reaction curves intersect with their downward sloping sections. A sufficient condition for this to occur is that $\beta_s e_s$ is not too small. Then, the equilibrium emission quotas are given as

$$E_n^0 = \frac{e_n}{3}(1 + \beta_s e_s - 2\beta_n e_n) \quad \text{and} \quad E_s^0 = \frac{e_s}{3}(1 + \beta_n e_n - 2\beta_s e_s).$$

Some interesting properties of the above equilibrium policies shall be particularly helpful in understanding the main results in the paper. They are summarized in the following lemma (the proof is straightforward):

Lemma 1. *In the case of no technology transfer, the equilibrium emissions quotas have the following properties*:

$$\text{(i)}\ \frac{\partial E_i^0}{\partial \beta_i} < 0,\ \frac{\partial E_i^0}{\partial \beta_j} > 0;\ \text{(ii)}\ \frac{\partial E_i^0}{\partial e_j} > 0;\ \text{(iii)}\ \frac{\partial Q_i^0}{\partial e_i} < 0.$$

Hence, a government's quota policy becomes more stringent (smaller E_i^0 or Q_i^0) if it cares more about pollution, its firm's technology becomes less clean, the other country cares less about pollution, or the other country's firm's technology becomes cleaner. The intuitions behind these results are as follows. First, the result of $\partial E_i^0/\partial\beta_i < 0$ is straightforward since (marginal) pollution damage is higher when β_i goes up. The result of $\partial E_i^0/\partial\beta_j > 0$ comes from the fact that the policy reaction functions are downward-sloping, i.e., the policies are strategic substitutes. Therefore, a larger β_j leads to a lower emissions quota in country j, which in turn gives rise to a higher emissions quota in country i.

Second, the effect of e_i on the equilibrium emissions quotas can be illustrated as follows. For example, a reduction of e_n would shift the Northern government's reaction curve upward but leave the Southern government's reaction curve unchanged, and we therefore have $\partial Q_n^0/\partial e_n < 0$ and $\partial Q_s^0/\partial e_n > 0$ (see Figure 3). The inequality $\partial Q_n^0/\partial e_n < 0$ indicates that the North will raise its (production) quota if its firm becomes cleaner. There are two forces that drive this result. The first is the strategic effect: when the firms engage in Cournot competition, a government wants to set a less restrictive policy (here, a larger quota) to help shift profits to its firm. The second force is the "carbon leakage" effect, which comes from the fact that the North also cares about the pollution generated by the South. With a cleaner technology, the North would benefit from encouraging its firm to produce more (through a larger quota) and encouraging the S-firm to produce less (the firms' strategy variables are strategic substitutes). Although it is desirable to have a production quota as large as possible due to the strategic effect, this desirability is constrained by the concern of increased pollution generated by the expanding firm. However, if the firm has cleaner technology, the "carbon leakage" effect suggests that the constraint becomes less serious. Note that we have an ambiguous sign for $\partial E_i^0/\partial e_i$ because a decrease in e_i and an increase in Q_i^0 can either increase or decrease $E_i^0 = e_i q_i^0 = e_i Q_i^0$. The results of $\partial E_i^0/\partial e_j < 0$ can be understood similarly.

Note that $Q_n^0 = Q_s^0$, i.e., symmetric (production) quotas and hence symmetric production in both countries, will emerge in equilibrium, if and only if $\beta_n e_n = \beta_s e_s$. However, that condition implies that the North has a stricter emissions quota than the South has, $E_n < E_s$. That is, the N-firm generates less pollution than the S-firm does. Also note that $Q_i^0 < 1/3$ if and only if $\beta_i e_i > \frac{1}{2}\beta_j e_j$. That is, compared with the situation of no pollution control, a firm is allowed to produce less because either its country cares a lot about pollution (especially in the Northern country's case if β_n is sufficiently large) or its technology is dirty (especially in the Southern country's case if e_s is sufficiently large). When $Q_i^0 < 1/3$ for $i = s$ and n, the firms' outputs in the final stage of the game are always binding: $q_i^0 = Q_i^0$.

To restrict the parameter values so that the observed scenario is attained, $E_n^0 < E_s^0$, we impose the following restriction/assumption:

$$\textbf{(A.2):} \qquad (e_s - e_n) + (\beta_n - \beta_s)e_n e_s + 2(\beta_n e_n^2 - \beta_s e_s^2) > 0.$$

2.2. The subgame with technology transfer

■ *Production stage.* We now turn to the right panel of the game tree in Figure 1, in which there is technology transfer in the first stage. Assume that the license fee, f, cannot be made contingent on the second-stage government policies. The fee is completely specified and the S-firm pays it to the N-firm before the second-stage game begins. Then, given $\{E, f\}$, the firms' profits are $pq_n + f$ and $pq_s - f$, respectively. Firms choose outputs to maximize their profits subject to the policy constraints, $q_i e_n \leq E_i$ (recalling that the S-firm also has e_n), or production constraints $q_i \leq Q_i$, now $Q_i = E_i / e_n$.

The derivation of the production stage equilibrium is the same as in the case of no technology transfer. Let q_i^T and π_i^T denote the third-stage equilibrium, outputs and profits (excluding license fees), with technology transfer. Then, the gross profits (including license fees) are $\pi_n^T + f$ and $\pi_s^T - f$, respectively

■ *Policy stage.* In the presence of technology transfer, the North's welfare is $W_n^T = \pi_n^T + f - \beta_n e_n(q_n^T + q_s^T)$ and the South's welfare is $W_s^T = \pi_s^T - f - \beta_s e_n(q_n^T + q_s^T)$. Replacing e_s with e_n and going through the same analysis as for the equilibrium policy in the case of no technology transfer, we need the following assumption [instead of (A.1)] to obtain similar reaction function curves as in Figure 3:

$$\textbf{(A.3)}: \qquad \beta_n \leq \frac{1}{3e_n}.$$

Then, we can easily obtain the equilibrium policies,

$$E_n^T = \frac{e_n}{3}(1 + \beta_s e_n - 2\beta_n e_n) \quad \text{and} \quad E_s^T = \frac{e_n}{3}(1 + \beta_n e_n - 2\beta_s e_n). \tag{2}$$

If we view policy restrictiveness from the firms' points of view, we should pay more attention to the production constraint (Q_i) than to the emissions constraints (E_i). By comparison, we have $Q_s^T - Q_s^0 = 2\beta_s(e_s - e_n)/3 > Q_n^0 - Q_n^T = \beta_s(e_s - e_n)/3 > 0$. That is, under technology transfer, the South sets a more lax policy while the North sets a more stringent policy, and the policy difference of the South is bigger than that of the North (this can be viewed from Figure 3 with an upward shift of the Southern government's reaction curve). The latter result implies $Q_n^T + Q_s^T > Q_n^0 + Q_s^0$. The reason for a less-restrictive total production quota under technology transfer is that the average technology becomes cleaner. It is clear that $E_n^0 > E_n^T$, but pollution emissions generated by the S-firm could go up or down after technology transfer since it has a cleaner technology but produces more output.

Proposition 1 (the proof is straightforward) below shows the ranking of the equilibrium quotas.

Proposition 1. *Compared with the case without technology transfer, under technology transfer* (i) *the Southern (resp. Northern) firm faces a less (resp. more) stringent production constraint* ($Q_s^T > Q_s^0$) *(resp.* $Q_n^T < Q_n^0$) *and the total production constraint is less restrictive* ($Q_n^T + Q_s^T > Q_n^0 + Q_s^0$); (ii) *the Northern pollution emissions quota is smaller* ($E_n^T < E_n^0$) *and the Southern pollution emissions quota is also smaller* ($E_s^T < E_s^0$) *iff* $1 + \beta_n e_n + 2\beta_s(e_n + e_s) > 0$; and (iii) *total pollution is lower* ($E_s^T + E_n^T < E_s^0 + E_n^0$) *iff* $1 + \beta_n e_n - \beta_s(e_n + 2e_s) > 0$.

2.3. Equilibrium choice on technology transfer

With the analysis in the previous two subsections, we are now ready to examine the first stage of the game regarding technology transfer.

Suppose the N-firm is willing to transfer its technology to the S-firm. Then, the two firms bargain over the price of the technology. Following Katz and Shapiro (1985), we assume that this price is a fixed fee, f.[9] Assuming that the N-firm's bargaining power is $\alpha \in (0, 1)$ and that of the S-firm is $1 - \alpha$, the equilibrium transfer price is given by $f^* = \text{argmax}\ (\pi_n^T + f - \pi_n^0)^\alpha(\pi_s^T - f - \pi_s^0)^{1-\alpha}$. Choosing f to maximize $(\pi_n^T + f - \pi_n^0)^\alpha(\pi_s^T - f - \pi_s^0)^{1-\alpha}$ or, equivalently, to maximize $\alpha\ln(\pi_n^T + f - \pi_n^0) + (1 - \alpha)\ln(\pi_s^T - f - \pi_s^0)$ yields the equilibrium fee

$$f^* = \alpha(\pi_s^T - \pi_s^0) + (1 - \alpha)(\pi_n^0 - \pi_n^T). \tag{3}$$

We now show that as a result of technology transfer and the second-stage policy changes, the S-firm gains in the market (i.e., $\pi_s^T > \pi_s^0$) while the N-firm loses (i.e., $\pi_n^0 > \pi_n^T$). All changes resulting from the technology transfer give rise to this market-profit redistribution. As shown in Proposition 1, technology transfer induces the South to relax its production constraint (from Q_s^0 to Q_s^T), while the North tightens its production constraint (from Q_n^0 to Q_n^T). This leads to an increase in profits for the S-firm and a reduction in profits for the N-firm. Because of this redistribution of market profits, the S-firm is required to pay ($f^* > 0$) to the N-firm for the technology. The equilibrium fee given by (3) is chosen to cover part of the N-firm's losses

[9] The basic insight of our analysis remains even when we consider a royalty fee for the technology transfer. The quantitative (not qualitative) aspect of the results nevertheless will be affected (the results are more complicated).

$(\pi_n^0 - \pi_n^T)$ and to share part of the S-firm's gains $(\pi_s^T - \pi_s^0)$, with the proportions determined according to the firms' relative bargaining power.

We now examine the key condition for technology transfer to take place. First, the S-firm is willing to pay for the Northern technology if and only if its return will be improved: $\pi_s^T - f^* - \pi_s^0 > 0$. Using (3), this condition is equivalent to

$$\pi_s^T - \pi_s^0 > \pi_n^0 - \pi_n^T \qquad \text{or} \qquad \pi_n^T + \pi_s^T > \pi_n^0 + \pi_s^0. \tag{4}$$

The interpretation of the above condition is simple: So long as the market-profit gain by the S-firm outweighs the market-profit loss of the N-firm, or the joint market profits with technology transfer are larger than those without, the S-firm is willing to pay f^* for the technology (Tirole, 1988). Second, the N-firm is willing to transfer its technology if and only if its return will be enhanced: $\pi_n^T + f^* - \pi_n^0 > 0$. It turns out that the condition is the same as (4). That is, the two firms have the same decision to make regarding whether or not to transfer the technology. The reason is that Nash bargaining with monetary transfer fully internalizes the negative effect on each other firm's payoff, resulting in the maximization of the joint profits.

Substituting in (4) with the equilibrium profits obtained from the previous two sections yields the necessary and sufficient condition for technology transfer in the first stage:

$$1 - (Q_n^T + Q_s^T) - (Q_n^0 + Q_s^0) > 0, \tag{5}$$

or, equivalently

$$1 - 2\beta_n e_n - \beta_s(e_n + e_s) < 0. \tag{6}$$

To understand the intuition, let us draw the industry profit curve (in Figure 4) as a function of total production. The intuition is as follows. As indicated by (4), we need to compare the joint profits with and without technology transfer. If there is no production constraint, the joint profit will be just the sum of the profits of two unconstrained Cournot firms, which is less than the monopoly profit if the market is supplied by a single firm, because the total production by the two Cournot firms is larger than that by the monopoly. Production quotas, however, reduce the Cournot firms' total production, which results in higher or lower joint profit, depending on the severity of the quotas. Specifically, there are two cases. First, the quotas are very restrictive, i.e., $(Q_n^0 + Q_s^0)$ is smaller than the unconstrained monopoly output. Recall that technology transfer makes the total production larger. If it is not too large, i.e., $Q_n^T + Q_s^T$ is still below the monopoly output, then technology transfer increases profits since the total output level is on the left-hand-side (LHS) (the upward sloping part) of the joint profit curve. Therefore, technology transfer will occur. It can be seen from (5) that, if none of the production quotas is large, then the condition holds. It can also be seen from (6) that the condition holds when β_n and β_s are both large, which is the reason for small quotas. However, the profits may actually drop if the total quotas after technology transfer exceed those before technology transfer to a large extent (then (5) does not hold), which is the case if e_n is very small (then (6) does not hold).

<Fig. 4 about here>

Second, the quotas are not too restrictive, i.e., $(Q_n^0 + Q_s^0)$ is larger than the unconstrained monopoly output. In this case, technology transfer makes the total production even larger and so reduces the total profits since the total output level is on the right-hand-side (RHS) (the downward sloping part) of the joint profit curve. Therefore, technology transfer will not occur. It can be seen from (5) that if the production quotas are too large, then the condition does not hold. It can also be seen from (6) that the condition does not hold when β_n and β_s are both small, which is the reason for large quotas.

For the purpose of this paper, we consider the case of no technology transfer as the initial equilibrium outcome, and we take this as a benchmark for the subsequent analysis in Section 3.

3. The Model in the Presence of an IEA

Since our focus is not on the formation of an IEA, we shall use a canonical setup. Suppose the left panel of Figure 1 (technology transfer does not take place) is the initial equilibrium, i.e., condition (6) does not hold and (E_n^0, E_s^0) is the current equilibrium policy. Now, let the North represent an existing IEA and let E_n^0 be the North's corresponding emissions level under the IEA. We will focus on the Southern government's decision to join the existing IEA (rather than bargaining with the North to form a new IEA). This is applicable to many current IEAs, which have the principle of open membership.

We characterize the expansion of the IEA (i.e., the South's joining) with the following three key elements: (1) the IEA accession requires the South to reduce its emissions level down to a fixed level, $E^m \in [E_n^0, E_s^0)$; (ii) there is a monetary transfer, R, from the North to the South; and (iii) the North is not allowed to raise its emissions level above E_n^0 (restricted by the existing IEA). A discussion here is useful. Note that we consider a general signatory condition in the sense that the South is required to reduce its pollution level, E^m, which does not have to be equal to or less than E_n^0. Since such a policy change lowers the South's welfare and raises the North's welfare because of transboundary pollution and competition in the product market, compensation from the North to the South is unavoidable. In the real world, compensation can take various forms. For simplicity, we consider only lump-sum monetary compensation, R. Since this is an expansion, not a formation, of an IEA, we do not allow the South to bargain with the North with regard to E^m and R. Therefore, these variables are assumed to be a fixed target and a fixed amount of monetary transfer. A reason for such an assumption is that we are more interested in the effect of technology transfer, rather than the other factors, on the Southern government's decision to join the IEA. It is obvious that the Southern government is more willing to accept the agreement if R is greater and E^m is larger (closer to E_s^0).

While many factors can affect the Southern government's decision to join an IEA, understanding the role of technology transfer is important. We are particularly interested in the following two questions. Will technology transfer facilitate the expansion of the IEA, or induce the South to join the IEA? Second, will the participation of the South in the IEA facilitate environmental technology transfer (in the private market)? We will investigate the answers to the first question in Section 3.1 and to the second question in Section 3.2.

3.1. Will technology transfer increase the South's incentive to join the IEA?

Notice that there are potentially three scenarios regarding the South's decision to join the IEA. Scenario 1: the South joins the IEA with or without technology transfer in the first stage; Scenario 2: the South does not join the IEA with or without technology transfer in the first stage; and Scenario 3: the South's decision to join the IEA is affected by the technology transfer in the first stage of the game. It is quite obvious that, for a sufficiently large R, Scenario 1 will be the result, while for a sufficiently small R, Scenario 2 will be the result. Technology transfer does not affect the South's decision in both cases. Since we are more interested in the role of technology transfer, Scenario 3 is the focus of our analysis in this section. The game that we will analyze is similar to Figure 1 with a modification to the policy stage. In the second stage, the Southern government first decides whether or not to join the IEA. If it joins, its policy will be E^m and the Northern emissions quota will be E_n^0 or smaller, and the game moves to the production stage. If it does not join, the policy decision will be just the same as that in Figure 1: the North and South choose their respective emissions standard non-cooperatively, and the game moves to the production stage.

■ *Without technology transfer in stage 1.* Let us first consider the subgame with no technology transfer taking place in stage 1. If the Southern government joins the IEA, its welfare is

$$W_s^{m0}(E^m) = \pi_s^{m0} - \beta_s(q_s^{m0} e_s + q_n^{m0} e_n) + R, \tag{7}$$

where $q_s^{m0} = Q^{m0} = E^m/e_s$, $q_n^{m0} = Q_n^0$, and $\pi_s^{m0} = (1 - Q^{m0} - Q_n^0)Q^{m0}$. The South's welfare is a function of its emissions quota (E^m) and the North's quota as well. Notice that after the South joins the IEA, the North is not allowed to raise its quota though it is allowed to reduce it. The North will however actually keep its quota unchanged at E_n^0 after the South joins the IEA and so we simply drop it from the expression. To see why the Northern government does not reduce its quota in response to the South's move, recall that without technology transfer and with the South's joining the agreement, the equilibrium quotas are $\{Q_n^0, Q_s^0\}$. The IEA requires that the South reduce its quota to Q^{m0}. Since the two policies are strategic substitutes, it is optimal for the Northern government to raise its quota. But the IEA constrains the Northern government from raising its quota. Therefore, the constrained equilibrium quotas are $\{Q_n^0, Q^{m0}\}$.

If the Southern government does not join the IEA in the policy stage, the two governments will set their quotas non-cooperatively. This case has been analyzed in Section 2 and the South's welfare is given by $W_s^0 = (1 - Q_n^0 - Q_s^0)Q_s^0 - \beta_s(Q_n^0 e_n + Q_s^0 e_s)$. Direct calculation yields the welfare difference

$$W_s^{m0}(E^m) - W_s^0 = R - \Delta w_s^0, \text{ where } \Delta w_s^0 \equiv \frac{1}{e_s^2}(E_s^0 - E^m)^2. \tag{8}$$

The South will join the IEA if and only if $R \geq \Delta w_s^0$. It is clear that the South is more willing to join the IEA if the requirement (E^m) is closer to its equilibrium policy without joining the IEA (E_s^0). Moreover, the South is more willing to join the IEA if the N-firm's technology becomes cleaner ($\partial \Delta w_s^0 / \partial e_n < 0$).

■ *With technology transfer in stage 1.* Now consider the subgame in which technology transfer occurs in stage 1. If the South decides to join the IEA, what is the Northern government's optimal quota? From Lemma 1, notice that there are two opposite forces if the North could adjust its policy. On the one hand, a better environmental technology for the South induces the North to lower its quota because of a reduction of the "carbon-leakage" effect. On the other hand, the reduction of the emissions quota in the South (from E_s^0 to E^m) induces the North to raise its emissions quota because of the strategic effect in the product market. There are two possibilities, either $E_n^m < E_n^0$ or $E_n^m \geq E_n^0$, depending on which of the two forces is dominant. Although the IEA does not forbid the North to lower its quota, in this subsection we shall derive our results using the more realistic case in which $E_n^m \geq E_n^0$. We can show that the necessary and sufficient condition for this inequality is $E^m < e_n E_s^0/e_s$.[10] That is, we are considering the case where the IEA is not a marginal request on the South to reduce its pollution level. In light of the IEA constraint, the North does not raise but keeps its emissions quota at E_n^0. In this case, the South's welfare is

$$W_s^{mT}(E^m) = \pi_s^{mT} - f^m - \beta_s e_n(q_s^{mT} + q_n^{mT}) + R, \tag{9}$$

where $q_s^{mT} = Q^{mT} = E^m/e_n$, $q_n^{mT} = Q_n^0$, $\pi_s^{mT} = (1 - Q^{mT} - Q_n^0)Q^{mT}$, and f^m is the license fee.

The South's welfare in the case of not joining the IEA is analyzed before. It is W_s^T. Direct calculation yields the welfare difference

$$W_s^{mT} - W_s^T = R - \Delta w_s^T, \text{ where } \Delta w_s^T \equiv \frac{1}{e_n^2}(E_s^T - E^m)^2 - \frac{\beta_s(e_s - e_n)(E^m + \beta_s e_n^2)}{3e_n}. \tag{10}$$

The South will join the IEA if and only if $R \geq \Delta w_s^T$. It is clear that the South is more willing to join the IEA if the requirement (E^m) is closer to its equilibrium policy without joining the IEA (E_s^T). Moreover, the South is more willing to join the IEA if the S-firm's initial technology becomes dirtier ($\partial \Delta w_s^T/\partial e_s < 0$).

We say that technology transfer induces the South to join the IEA if and only if the Southern government does not want to join the IEA without technology transfer but it does want to join with technology transfer. Specifically, the conditions are that there exists R such that $\Delta w_s^T < R < \Delta w_s^0$. This requires $\Delta w_s^T < \Delta w_s^0$, which is

$$3e_n^2(E_s^0 - E^m)^2 > 3e_s^2(E_s^T - E^m)^2 + \beta_s e_n e_s^2(e_s - e_n)(E^m + \beta_s e_n^2). \tag{11}$$

[10]Note that the Northern government's reaction function is $Q_n^T(E^m) = (e_n - E^m - \beta_n e_n^2)/2e_n$. From $e_n Q_n^T(E^m) = E_n^m \geq E_n^0 = e_n(1 + \beta_s e_s - 2\beta_n e_n)/3$, we have $E^m < e_n E_s^0/e_s$.

If the above condition does not hold, then technology transfer can never induce the South to join the IEA if it does not join without technology transfer.

From the above analysis, we can see that to focus on Scenario 3 we should assume $R \in (\Delta w_s^T, \Delta w_s^0)$. Hence, we establish the following proposition.

Proposition 2. *Technology transfer induces the South to join the IEA if and only if condition (11) holds and* $R \in (\Delta w_s^T, \Delta w_s^0)$.

In fact, if condition (11) holds, then there always exist a range of R (some IEAs) such that technology transfer induces the South's IEA participation. Will condition (11) ever hold? The answer is yes. Suppose $1 + \beta_n e_n - 2\beta_s(e_n + e_s) > 0$ and $E^m = E_s^T < E_s^0$. Then, the condition is reduced to $2(e_s - e_n)[1 + \beta_n e_n - 2\beta_s(e_n + e_s)]^2 > 3\beta_s e_s^2(1 + \beta_n e_n + \beta_s e_s)$, which clearly holds for sufficiently small β_s.

However, it is important to note that condition (11) does not always hold. In particular, if in the absence of IEAs, technology transfer actually leads to a higher pollution level generated by the S-firm, i.e., $E_s^T > E_s^0$, which is the case when $1 + \beta_n e_n - 2\beta_s(e_n + e_s) < 0$ as shown in Proposition 1. Condition (11) does not hold. In this case, if we depart from Scenario 3 to allow $R > \Delta w_s^0$. Then, for the IEAs with $R < \Delta w_s^T$, the South is willing to join without technology transfer, but is not willing to join with the technology transfer. If this occurs, we say that technology transfer is a barrier to the South's IEA participation. Hence, we have the following corollary.

Corollary 1. *Suppose* $1 + \beta_n e_n - 2\beta_s(e_n + e_s) < 0$ and $R \in (\Delta w_s^0, \Delta w_s^T)$. *Then, technology transfer becomes a barrier to (i.e., it discourages) the South's IEA participation.*

Note that the target distance (i.e., the difference between the required IEA level, E^m, and the equilibrium level in the absence of the IEA, E_s^0 or E_s^T) is an important factor to determine the South's IEA incentives. In summary, *technology transfer could either increase or reduce the South's incentive to join an existing IEA.* Therefore, the timing of the technology transfer is important. That is, the technology transfer by the IEA member countries should be made before a developing country becomes a signatory of the IEA when the technology transfer raises the participation incentive, but it should be made after the country commits to joining the IEA when technology transfer reduces the participation incentive.

■ *Technology transfer decision.* Finally, we turn to examining the technology transfer decision in stage 1. Note that if conditions stated in Proposition 2 do not hold, then the South will not join the IEA with or without technology transfer in the first stage. Hence, in stage 1, the firms face the same situation as they do in section 2 (the non-IEA regime) and so the technology transfer does not occur since (6) does not hold.

However, if the conditions stated in Proposition 2 hold, the firms know that their technology transfer decision affects the Southern government's IEA participation. Thus, the condition for technology transfer is: the sum of the two firms' profits with technology transfer (and so with the IEA) is greater than that without technology transfer (and so without the IEA), i.e., $\pi_n^{mT} + \pi_s^{mT} > \pi_n^0 + \pi_s^0$. Substituting in the profit functions and collecting terms, this condition reduces to

$$(\beta_n e_n^2 - E^m)(\frac{e_n}{e_s} E_s^0 - E^m) < 0. \tag{12}$$

It is clear that the above condition holds iff $\beta_n e_n^2 < \frac{e_n}{e_s} E_s^0$ and $E^m \in (\beta_n e_n^2, \frac{e_n}{e_s} E_s^0)$. The former inequality holds iff $1 - 2\beta_n e_n - 2\beta_s e_s > 0$. We summerize the above analysis in Proposition 3.

Proposition 3. *Suppose (11) holds and* $R \in (\Delta w_s^T, \Delta w_s^0)$*. Then, technology transfer occurs in stage 1 iff* $1 - 2\beta_n e_n - 2\beta_s e_s > 0$ *and* $E^m \in (\beta_n e_n^2, \frac{e_n}{e_s} E_s^0)$*. Under these conditions, the South joins the IEA.*

When either of the two conditions in Proposition 3 does not hold, technology transfer will not occur and the South will not join the IEA. If, however, we allow the governments to subsidize the technology transfer, we would be able to see the result when technology transfer occurs and the South joins the IEA.

3.2. Will the South's participation in the IEA facilitate technology transfer?

We have argued that the decision of transferring technology cannot be reversed, but the decision of not transferring technology can be reversed. Correspondingly, we expand the game analyzed before. Figure 5 depicts such a game. Note that branches A and B capture the case when the non-transfer decision is allowed to be reversed after the South decides to join the IEA. Also, note that the game excluding these two paths is the game that we analyzed in Subsection 3.1. Thus, let us focus on the analysis of branches A and B, which, in fact, helps us to answer the question of if the South's participation in the IEA will facilitate technology transfer.

<Fig. 5 about here>

Given that the South has determined to join the IEA, technology transfer occurs if the joint profits with technology transfer, $\pi_n^{mT} + \pi_s^{mT}$, are larger than the joint profits without technology transfer, $\pi_n^{m0} + \pi_s^{m0}$. Substituting in the profit functions, this comparison is reduced to

$$1 - 2Q_n^0 - E^m(\frac{1}{e_n} + \frac{1}{e_s}) > 0. \tag{13}$$

The condition is more likely to hold for a smaller E^m. This is easy to see because a more stringent quota makes the S-firm more willing to pay for a better technology.

We say that the South's IEA participation facilitates technology transfer when (6) does not hold, but (13) does. Proposition 4 below shows that the South's participation in the IEA may or may not facilitate technology transfer, depending on the level of E^m.

Proposition 4. *Suppose (6) does not hold, e_n is small, and $\beta_n e_n > \beta_s e_s$. Then, there exists a critical $\bar{E} \in (E_n^0, E_s^0)$ such that the South's IEA participation facilitates technology transfer iff $E^m \leq \bar{E}$.*

Proof. See Appendix (ii). □

From Figure 4, the intuition for this proposition is not difficult to see. Since firms are not willing to have technology transfer in the absence of an IEA, this implies that the production quotas are not severe enough and the total production exceeds the unconstrained monopoly output, i.e., its is on the downward sloping part of the single-firm profit function as we discussed earlier. If E^m is not much different from E_s^0, the South's IEA participation will not make production quotas much tighter. The total production is still on the downward sloping part of the monopoly profit function. In this case, technology transfer will reduce total profits and so it will not take place. However, if E^m is sufficiently small, the total production will actually switch to the other side of the profit function, i.e., on the upward slope of the monopoly profit curve. As a result, technology transfer enlarges total production and total profits and, hence, it takes place. Therefore, the above proposition says that the South's IEA participation facilitates technology transfer when and only when the agreement is drastic enough (i.e., it requires the South to reduce its pollution emissions by a lot).

Proposition 4 generates a useful policy implication: in the case when the South's IEA participation alone does not facilitate technology transfer, the North should not only provide monetary transfer (R) to the South for joining the IEA but should also allow the Southern government to subsidize the technology transfer. Monetary transfer is made from the Northern to the Southern government to compensate the latter for reducing its pollution. The S-firm suffers from a lower emissions quota, but it is one of the players making the technology transfer decision. Hence, without an appropriate subsidy, the S-firm will not implement the technology transfer. This provides a strong support for the argument that, in addition to monetary transfer, *IEAs should allow the Southern government to subsidize (or, more generally, assist) its firms for environmental technology transfer.* This policy implication in fact is consistent with the existing WTO rules that allow subsidies to facilitate adaptation to new environmental technologies and regulations (e.g., see Hoekman and Kostecki, 1995, pp.104-109).

Finally, we complete the analysis of branches A and B by looking at the Southern government's decision in stage 2. First, if the South's IEA participation cannot facilitate technology transfer (i.e., any one condition in Proposition 4 fails), the Southern government will not participate in the IEA if $R < \Delta w_s^0$. Second, suppose $R \in (\Delta w_s^T, \Delta w_s^0)$, $E^m \leq \bar{E}$ and all other conditions in Proposition 4 hold so that South's IEA participation facilitates technology transfer. Then, the Southern government needs to compare the welfare under IEA participation with technology transfer ($W_s^{mT}(E^m)$ as given in (9)) and the welfare under no IEA participation and no technology transfer (W_s^0). We characterize conditions for IEA participation in Proposition 5 below.

Proposition 5. *Suppose (6) does not hold but (11) does, e_n is small, $\beta_n e_n > \beta_s e_s$ and $R \in (\Delta w_s^T, \Delta w_s^0)$. Then, if $R - f^m \geq 0$, there exists a critical $\tilde{E} \in (E_n^0, \bar{E})$ such that the South joins the IEA in stage 2 and technology transfer occurs subsequently if and only if $E^m \in (\tilde{E}, \bar{E})$.*
Proof. See Appendix (iii). □

From the proof in the appendix, we can see that $\tilde{E}$ is a decreasing function of $(R - f^m)$. This provides the intuition for why $R - f^m \geq 0$ serves as a sufficient condition for the existence of $\tilde{E}$. In fact, the sufficient and necessary condition for the existence of $\tilde{E}$ is that $(R - f^m)$ is not significantly negative. If R decreases, the Southern government's incentive to join the IEA is reduced, regardless of whether or not its IEA participation is able to induce technology transfer. If f^m increases, the benefit to the South from technology transfer is reduced and so the South is less willing to induce technology transfer by participating in the IEA.

4. Discussion

■ **Pollution tax.**

To achieve some pollution targets, pollution taxes can be used as a policy instrument, as opposed to pollution quotas (e.g., Hoel, 1992). How would the previous results be affected if the IEA is modeled as an increase in pollution taxes?[11] In a working paper (Qiu and Yu, 2003), we explore the technology transfer and IEA issues focusing on pollution taxes. Below, we report some of those results, focusing on the comparison of the results under quotas and taxes.

Suppose that the Northern government imposes an environmental tax, denoted t_n, on each unit of pollution generated by the N-firm. The corresponding tax imposed by the Southern government is assumed to be t_s. Let us first analyze the model without an IEA. In the absence of technology transfer, a country's welfare is

$$W_i^0 = \pi_i^0 - \beta_i(q_i^0 e_i + q_j^0 e_j) + t_i e_i q_i^0.$$

It is straightforward to compute the equilibrium policies, denoted t_n^0 and t_s^0,

$$t_i^0 = \frac{1}{5e_i}[4(2e_i - \gamma e_j)\beta_i - (2e_j - \gamma e_i)\beta_j - 1] = \frac{1}{5e_i}[(8\beta_i + \gamma\beta_j)e_i - 2(\beta_j + 2\gamma\beta_i)e_j - 1].$$

Lemma 2. *The equilibrium pollution taxes in the case of no technology transfer have the following properties:*

$$(i)\ \frac{\partial t_i^0}{\partial \beta_i} > 0,\ \frac{\partial t_i^0}{\partial \beta_j} < 0; \qquad (ii)\ \frac{\partial t_i^0}{\partial e_i} > 0,\ \frac{\partial t_i^0}{\partial e_j} < 0.$$

These properties are in line with those in Lemma 1 for the equilibrium quotas. A country's policy is more restrictive if it dislikes pollution and its technology becomes dirty. We focus on the case where $t_n^0 > t_s^0$.

[11] E.g., Ulph (1999) examines the effects of different environmental policy instruments.

In the case when technology transfer occurs in the first stage, the equilibrium taxes are

$$t_i^T = \frac{1}{5e_n}[e_n(2-\gamma)(4\beta_i - \beta_j) - 1].$$

By comparison, we obtain

Proposition 6. *(i) The Southern (resp. Northern) pollution tax is lower (resp. higher) with technology transfer than without, that is,* $t_s^T < t_s^0$ and $t_n^T > t_n^0$. *(ii) The difference between the tax with technology transfer and that without is larger for the South than for the North:* $\Delta t_s > \Delta t_n$.

Like Proposition 1, which is the corresponding proposition for emission quotas, Proposition 6 also serves to provide the intuition for the effects of technology transfer on the South's IEA participation and vice versa. The results in the two propositions are qualitatively the same.

We then define an IEA as an agreement that the North does not lower its pollution tax below t_n^0, the South adopts a pollution tax, $t^m \in (t_s^0, t_n^0]$, and there is a monetary transfer, R, from the North to the South. Then we obtain the necessary and sufficient condition for technology transfer to facilitate the South's IEA participation as

$$2e_s^2(t^m - t_s^0)^2 - 2e_n^2(t^m - t_s^T)^2 - e_n(t_n^T - t_n^0)[2 + (t_n^0 + t_n^T - t^m)e_n - 3\beta_s e_n(1-2\gamma)] > 0.$$

As in the emissions quota case, (11), the position of the IEA-required policy level, t^m, is a critical (but not the sole) factor affecting this condition. Technology transfer could either increase or reduce the South's incentive to join an existing IEA. This result has also been obtained for emissions quotas.

Turning to the effects of the IEA on technology transfer, we find that the IEA facilitates technology transfer iff

$$(t^m - t_s^0)[5e_n(t^m + t_s^0) - 8e_n t_n^0 - 2] - A > 0,$$

where $A \equiv (\Delta t_s - \Delta t_n)[2(1 - 2t_s^0 e_n + t_n^0 e_n) + 3e_n(\Delta t_s + \Delta t_n)] + 6e_n(t_n^0 - t_s^0)(\Delta t_s + 2\Delta t_n)$, $\Delta t_s \equiv t_s^0 - t_s^T$ and $\Delta t_n \equiv t_n^T - t_n^0$. However, we show that this condition never holds. That is, the IEA does not facilitate technology transfer. This result is different from that for emissions quotas (Propositions 4 and 5). The reason for such a difference stems from the different effects of quota and tax policies on the firms' total profits. While the IEA in both cases reduces total production and thus facilitates collusion, the collusive result is achieved in a more expensive way (from the firms' point of view) in the tax case than in the quota case. Hence, in the case of pollution taxes, the IEA does not bring a net benefit to the firms and so technology transfer does not occur after the South's IEA participation if it does not occur without the South's IEA participation.

■ **Abatement technology.**

In the main model, each region's technology creates a fixed level of pollution per unit of output. In the absence of technology transfer, the only way for a firm to reduce its total pollution level is to reduce its output. In the presence of technology transfer, the S-firm's pollution level is reduced without reducing the output. However, there is no abatement technology that can be adopted by a firm to reduce its pollution level. We now discuss the effects of introducing an abatement technology on results obtained from our main model.

Let us first look at some analytical difficulties arising from exploring the technology transfer and IEA issues with abatement technologies. One way to model adoption of abatement technologies is as follows. To capture that the two regions have different abatement technologies, let us assume $e_n = e_s = 1$; that is, both firms have the same level of pollution emitted from per unit of output. To reduce its total pollution by α units, firm i needs to invest $\frac{1}{2}c_i a^2$ dollars, with $0 < c_n < c_s$. In this sense, we say that the N-firm has a more efficient (better) abatement technology than the S-firm has. Then, given pollution quotas, E_i, firm i chooses q_i and α_i to maximize its profits, $(pq_i - \frac{1}{2}c_i\alpha_i^2)$, subject to $q_i + \alpha_i \leq E_i$. A firm has some flexibility between output and emissions to satisfy the quota constraint. It should not be too difficult to characterize the Cournot-Nash constrained equilibrium with each firm having two strategic variables. However, it is very difficult to derive the policy equilibrium for the earlier stage of the game, and even more difficult to obtain useful conditions for technology transfer in the first stage of the game. The complete analysis of such a game would require a separate paper. For this reason, let us focus on a very special case of abatement technology to see how our results are likely to be altered and in what ways.

Assume firm i can adopt an abatement technology to reduce pollution to $(1 - a_i)$ per unit of output. There is a fixed cost, K, of adopting and utilizing technology. Assume $a_n > a_s$ and also that the N-firm has a better abatement technology than the S-firm has. Suppose there is no technology transfer in the first stage and no IEA. Given quotas $\{E_n, E_s\}$, the firms in the final stage of the game then choose whether or not to adopt their own abatement technologies and their output levels. If it does not adopt the abatement technology, firm i's problem is to choose q_i to maximize $\pi_i^0 = p(q_i, q_j)q_i$ subject to $q_i \leq E_i$; if it adopts the abatement technology, its problem is to choose q_i to maximize $\pi_i^a = p(q_i, q_j)q_i - K$ subject to $q_i(1 - a_i) \leq E_i$. The firm then compares the two suboptimal profits. Note that other things being equal, the N-firm is more likely to choose the abatement technology than the S-firm is. Moreover, if β_n is very large, E_n will be quite small and the N-firm's dominant strategy is to adopt the abatement technology; if β_s is very small, E_s will be quite large and the S-firm's dominant strategy is not to adopt the abatement technology. This is an interesting equilibrium to focus on.

How will the technology transfer condition change in the above-mentioned environment, in the absence of an IEA? Suppose the S-firm would not adopt the abatement technology if the technology transfer does not occur in the first stage. Then, the analysis of the technology transfer is exactly the same as that in subsection 2.3. The threat point profits, π_i^0, are obtained when the N-firm adopts its abatement technology but the S-firm does not. As a result, the necessary and sufficient condition for technology transfer is still the same as (5), but the expression of (6) becomes $1 - 2\beta_n(1 - a_n) - \beta_s(2 - a_n) < 0$.

Suppose the S-firm would adopt the abatement technology even if the technology transfer does not occur in the first stage. This will be the case if e_s and β_s are not very small. The difference between this case and the previous one lies in the threat point profits, π_i^0, which now are obtained when both firms adopt their abatement technologies. As a result, the necessary and sufficient condition for technology transfer is still the same as (5), but the expression of (6) becomes $1 - 2\beta_n(1 - a_n) - \beta_s(2 - a_n - a_s) < 0$. It is easy to see that this condition is stronger than the previous one. That is, technology transfer is less likely because the S-firm will use its own abatement technology if the technology transfer does not occur and so is less willing to pay for the Northern technology.

Given the above analysis, it is not difficult to see that the results obtained in Propositions 2-5 are unlikely to be altered qualitatively when abatement technologies are added to the model. Nevertheless, we admit that the above discussion is based on a very special type of abatement technology. Without further analysis, we cannot make such a claim in general for the case with abatement technologies.

5. Concluding Remarks

Contrary to the commonly shared view that environmental technology transfer would help induce developing countries to join international environmental agreements (since with their existing technology they are simply not able to afford to improve their environmental standards), we show that environmental technology transfer could either increase or reduce the South's incentives to join an existing IEA. This is the main message of our paper. Although we derive the result in a very specific model (a partial equilibrium model with imperfect competition and hence we must be cautious in discussing general policy implications), the policy implications of our result are relevant and valid. The purpose of this paper is to provide a cautionary note to the general view and hence our specific model should suffice to make the point. We also show that the South's commitment to join the IEA may reduce the market incentive for technology transfer and, therefore, developing countries should be allowed to subsidize their firms for environmental technology transfer.

Appendix

(i). *Analysis of equilibrium quotas in the absence of technology transfer (Figure 3).*

Let us derive the Northern government's best response to the Southern government's policy, Q_s. First, for $Q_s \geq \frac{1}{3}$, we have case 1 if the Northern government chooses $Q_n \geq \frac{1}{3}$, and case 3 if $V_n < \frac{1}{3}$. In case 1, the welfare for the North is $W_n^{01} = \frac{1}{9} - \frac{1}{3}\beta_n(e_n + e_s)$. In case 3, the equilibrium output is $q_n^* = Q_n$ and $q_s^* = \min\{Q_s,\ (1 - Q_n)/2\}$. The Northern government chooses Q_n to maximize $W_n^{03} = (1 - Q_n - q_s^*)Q_n - \beta_n(Q_n e_n + q_s^* e_s)$. For $Q_n \in (1 - 2Q_s,\ \frac{1}{3})$, $\partial W_n^{03}/\partial Q_n = \frac{1}{2}(1 - 2Q_n) - \frac{1}{2}\beta_n(2e_n - e_s) > 0$ if $2e_n \leq e_s$ or β_n is sufficiently small. We therefore impose assumption (A.1). For $Q_n \in (0,\ 1 - 2Q_s]$, W_n^{03} reaches its optimum at $Q_n = (1 - Q_s - \beta_n e_n)/2$ provided $Q_s < \min\{(1 + \beta_n e_n)/3,\ 1 - \beta_n e_n\}$. By comparing W_n^{03} at its optimum in $(0,\ 1 - 2Q_s]$ to W_n^{01}, there exists a unique $r_s^0 \in (\frac{1}{3},\ \frac{1+\beta_n e_n}{3})$ such that $W_n^{03*} > W_n^{01}$ iff $Q_s < r_s^0$.

Second, for $Q_s < \frac{1}{3}$, we have case 2 if $Q_n < \frac{1}{3}$ and case 4 if $Q_n \geq \frac{1}{3}$. In case 2, the welfare in the North is $W_n^{02} = (1 - Q_n - Q_s)Q_n - \beta_n(Q_n e_n + Q_s e_s)$. In case 4, the equilibrium output is $q_s^* = Q_s$ and $q_n^* = \min\{Q_n, (1 - Q_s)/2\}$. The Northern government chooses Q_n to maximize $W_n^{04} = (1 - Q_s - q_n^*)q_n^* - \beta_n(q_n^* e_n + Q_s e_s)$. It turns out that both W_n^{02} and W_n^{04} reach maximum at $Q_n = (1 - Q_s - \beta_n e_n)/2$.

Summarizing the above analysis, we obtain the Northern government's best response to any given Q_s as shown in Figure 3.

We now turn to deriving the Southern government's best response to the Northern government's policy, Q_n. First, for $Q_n \geq \frac{1}{3}$, we have case 1 if the Southern government chooses $Q_s \geq \frac{1}{3}$, and case 4 if $Q_s < \frac{1}{3}$. In case 1, the welfare in the South is $W_s^{01} = \frac{1}{9} - \frac{1}{3}\beta_s(e_n + e_s)$. In case 4, the equilibrium output is $q_s^* = Q_s$ and $q_n^* = \min\{Q_n, (1 - Q_s)/2\}$. The Southern government chooses Q_s to maximize $W_s^{04} = (1 - Q_s - q_n^*)Q_s - \beta_s(q_n^* e_n + Q_s e_s)$. For $Q_s \in (1 - 2Q_n, \frac{1}{3})$, $\partial W_s^{04}/\partial Q_s = \frac{1}{2}(1 - 2Q_s) - \frac{1}{2}\beta_s(2e_s - e_n) > 0$ if β_s is sufficiently small, hence imposing assumption (A.1). For $Q_s \in (0, 1 - 2Q_n]$, W_s^{04} reaches its optimum at $Q_s = (1 - Q_n - \beta_s e_s)/2$ provided $Q_n < \min\{(1 + \beta_s e_s)/3, 1 - \beta_s e_s\}$. By comparing W_s^{04} at its optimum in $(0, 1 - 2Q_n]$ to W_s^1, there exists a unique $r_n^0 \in (\frac{1}{3}, \frac{1+\beta_s e_s}{3})$ such that $W_s^{04*} > W_s^{01}$ iff $Q_n < r_n^0$.

Second, for $Q_n < \frac{1}{3}$, we have case 2 if $Q_s < \frac{1}{3}$ and case 3 if $Q_s \geq \frac{1}{3}$. In case 2, the welfare in the South is $W_s^{02} = (1 - Q_n - Q_s)Q_s - \beta_s(Q_n e_n + Q_s e_s)$. In case 3, the equilibrium output is $q_n^* = Q_n$ and $q_s^* = \min\{Q_s, (1 - Q_n)/2\}$. The Southern government chooses Q_s to maximize $W_s^{03} = (1 - Q_n - q_s^*)q_s^* - \beta_s(Q_n e_n + q_s^* e_s)$. It turns out that both W_s^{02} and W_s^{03} reach their maximums at $Q_s = (1 - Q_n - \beta_s e_s)/2$.

Summarizing the above analysis, we obtain the Southern government's best response to any given Q_n, as shown in Figure 3.

The equilibrium policies are determined by the intersection of the two reaction curves, R_n^0 and R_s^0, as shown in Fig. 3. The expressions of E_n^0 and E_s^0 can be easily calculated. $\square$

(ii). *Proof of Proposition 4.*

Denote the LHS of (13) using a function, $T(E^m)$. First, note that $T(E^m)$ is continuous and decreasing in E^m.

Second, suppose $E^m = E_s^0$. Then, $T(E_s^0) = 1 - 2Q_n^0 - Q_s^0 - E_s^0/e_n$. Recall from Proposition 1 that $Q_n^T < Q_n^0$ and $E_s^T < E_s^0$. Hence, $T(E_s^0) < 1 - (Q_n^0 + Q_n^T) - Q_s^0 - Q_s^T < 0$, where the second inequality holds because there is no technology transfer in the absence of IEA according to (5).

Third, suppose $E^m = E_n^0$. Then, we can rewrite $T(E_n^0) = -e_n(1 - 2\beta_n e_n - \beta_s e_s - \beta_s e_n) + 2(\beta_n - \beta_s)e_n e_s + e_n(\beta_n e_s - \beta_s e_n) + 3e_s(\beta_n e_n - \beta_s e_s)$. Note that the first term is negative because the term in the bracket is positive (no technology transfer without IEA) according to (6); the second and third terms are both positive; and the last term is positive under the supposition of the proposition. Hence, $T(E_n^0) > 0$ provided that e_n is sufficiently small under the supposition of the proposition.

The above analysis shows the existence of $\bar{E}$ with the property stated in the proposition. □

(iii). *Proof of Proposition 5.*

Based on Proposition 4, the conditions that (6) does not hold, e_n is small, $\beta_n e_n > \beta_s e_s$, $R \in (\Delta w_s^T, \Delta w_s^0)$ and $E^m < \bar{E}$ ensure technology transfer so long as the South participates in the IEA. However, the South does not do so unless $W_s^{mT}(E^m) > W_s^0$. Using the expressions we obtained before for these two welfare functions, we can rewrite them as $W_s^{mT}(E^m) = f(E^m) + R - f^m$ and $W_s^0 = f(e_n Q_s^0) - \beta_s E_s^0 + \beta_s e_n Q_s^0 = f(e_n Q_s^0) - \beta_s(e_s - e_n)Q_s^0$, where

$$f(x) \equiv \frac{1}{e_n^2}[\beta_s e_n^2 E_n^0 + (e_n - E_n^0 + \beta_s e_n^2)x - x^2].$$

To compare $W_s^{mT}(E^m)$ and W_s^0, let us draw two curves: $W_s^{mT}(x) = f(x) + R - f^m$ and $W_s^0(x) = f(x) - \beta_s E_s^0 + \beta_s x$. Note that $W_s^0(x) < f(x)$ and if $R - f^m \geq 0$, then $W_s^{mT}(x) \geq f(x)$. Also note that $W_s^0 < W_s^{mT}(0)$. The existence of $\tilde{E}$ and the rest of the proof becomes straightforward by looking at the graph in Figure 6. □

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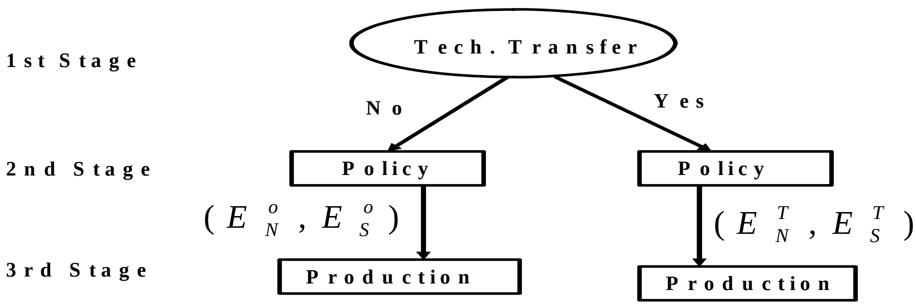

Figure 1: Sequence of Moves

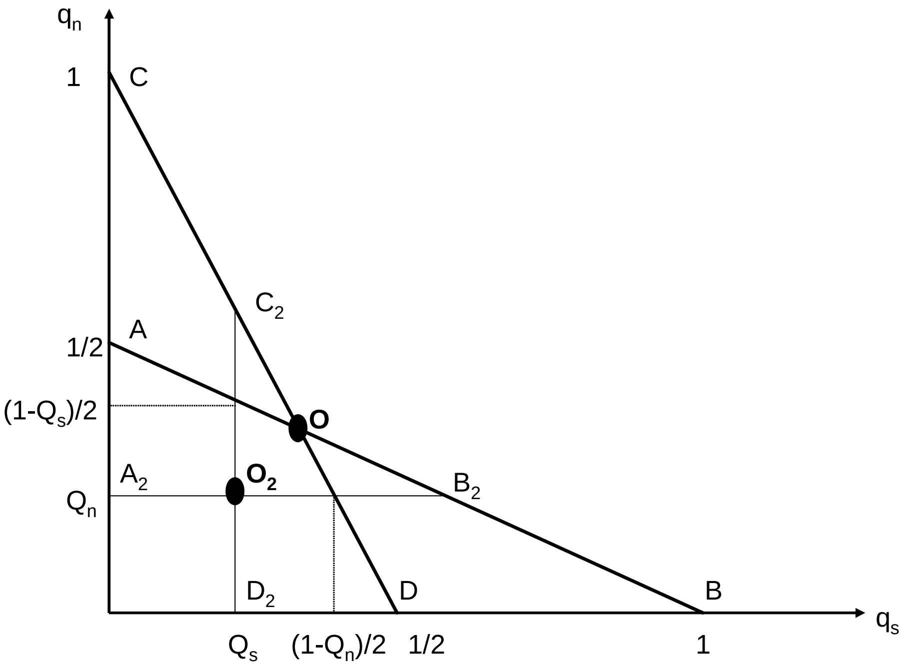

Figure 2: Constrained Reaction Curves

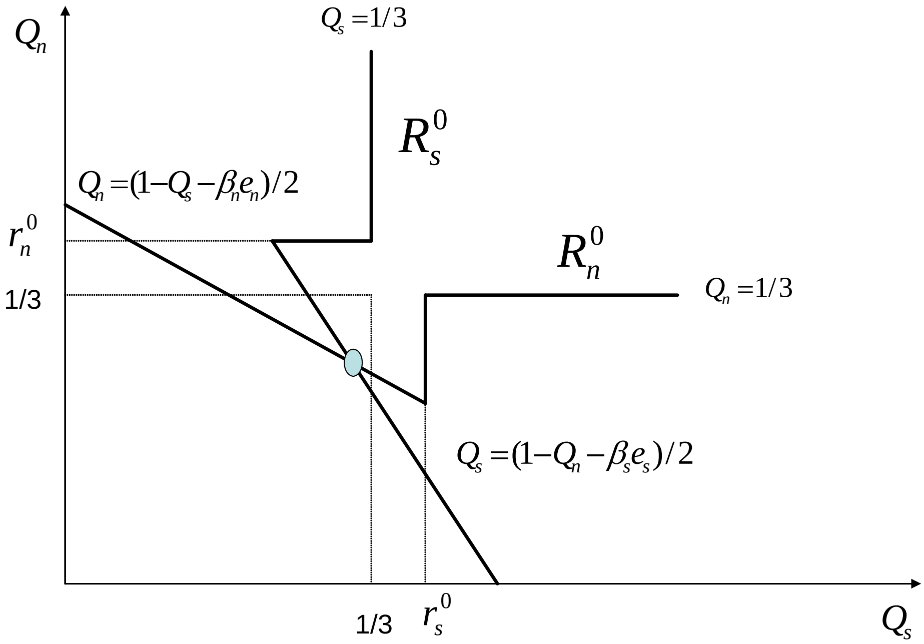

Figure 3: Policy Reaction Curves

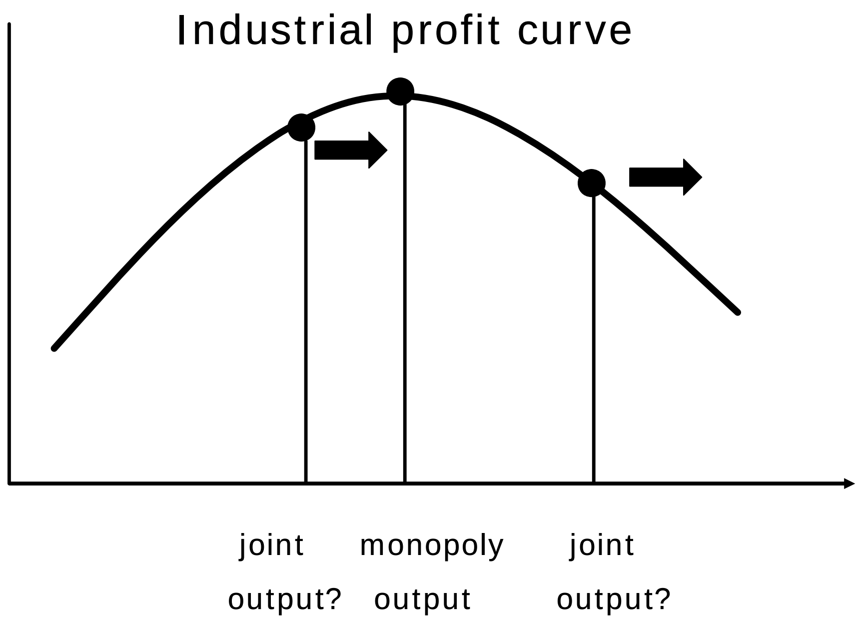

Figure 4: Intuition for the Technology Transfer Decision

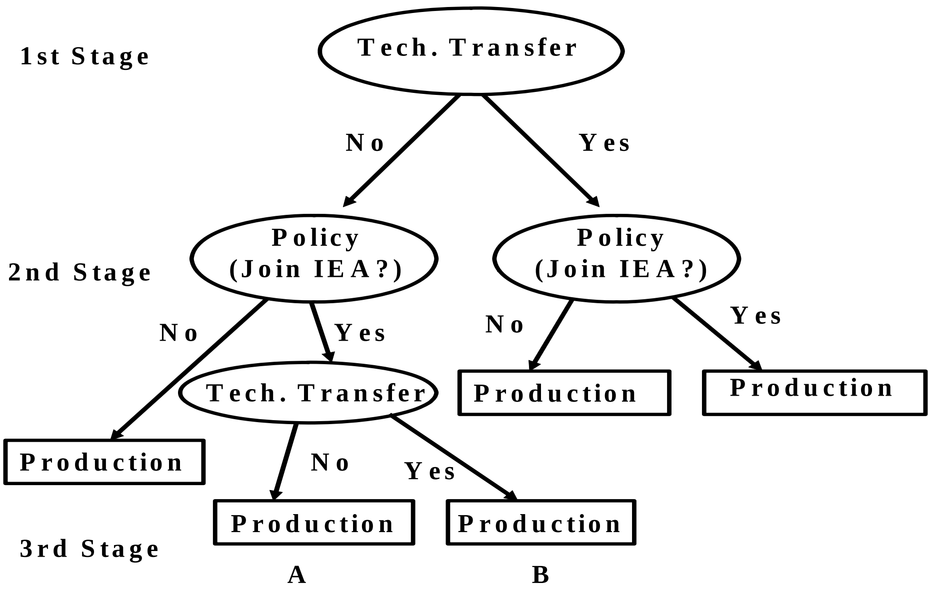

Figure 5: Sequence of Moves (2)

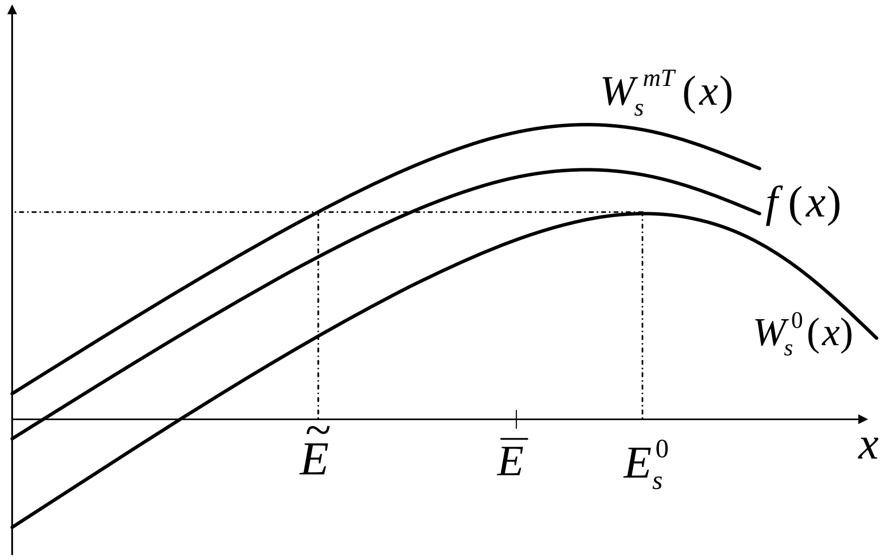

Figure 6: Welfare Comparison