The incentives to North-South transfer of climate-mitigation technologies with mobile firms

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Abstract

This paper investigates the relation between the firms' incentives to relocate and the countries' incentives to transfer climate-mitigation technologies.

JEL codes:

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1 Introduction

Climate Change is probably the most pressing challenge felt throughout the world. While requiring the implementation of environmental regulations across the world, it is conditioned by local realities that decision makers have to face. Developing countries are still reluctant to implement environmental regulations. In particular they often denounce the unequal burden sharing, claiming that climate change policies are too constraining in terms of costs and growth. A promising

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avenue proposed during COP 16 consists in enhancing the transfer of green technologies from developed countries to developing countries. However,these unilateral policies may indeed increase the production costs and push firms to relocate their activities in less environmentally-friendly countries, which in turn would generate an increase in total emissions and also a deindustrialization. It therefore transpires that a crucial question relating to the environmental cooperation is the relation between the firms' incentives to relocate and the countries' incentives to transfer climate-mitigation technologies.

Green technologies are concentrated in developed countries. For instance, according to Dechezlepretre et al (2011)(5), between 2000 and 2005 two third of the newly developed technologies were patented in USA, Germany and Japan. In 2012, developing countries such as China, India and Mexico produced almost 70% of the world's CO2 emissions. Being potentially highly beneficial for developing countries, the transfer of green technologies raises nevertheless serious obstacles for developed countries. Indeed, sharing technological innovation may enable developing countries' firms to reduce more rapidly the technological gap with developed countries and also to become more competitive and gain market shares. Glachant et al (2016)(10) show that technology transfer commitments can be used as a substitution of monetary transfers, given to convince developing countries to ratify environmental regulations. Nevertheless, we focus in this paper on another consequence of the technological transfer, that is to reduce the relocation risk.

Relocation can be particularly detrimental for a country. Indeed, relocation induces a destruction of human and physical capitals, leading to a loss of specific knowledge and skills. Indeed, relocation by causing unemployment is particularly costly for countries. Moreover, relocation generates also an increase in foreign emissions. Indeed, firms which relocate in countries implementing more lenient environmental regulations contribute to increase foreign emissions. Like transfer of technologies, foreign development investments eases the diffusion of knowledge and technologies. Said differently, relocation is one of the channels leading to technological transfer. One major differences between technological transfer and relocation is that the latter is only decided firms while the first may be the result of decisions taken either by firms or governments.

Various tools may be used to prevent firms from relocating. subsidies For instance, Martin et al (2014)(21) determine the number of free allowances that are sufficient to prevent firms from relocating. Another solution could be to for the government to purchase goods to firms that are exposed to a high risk of relocation. Nationalizing those firms is also an alternative since it may prevent them easily from closing their domestic plants but is politically sensitive. The goal of this paper is to show that the transfer of clean technologies from a developed country to a developing country may reduce the incentives of firms to relocate.

In this paper, the technology transfer that we consider is such as the technology from the developed country is being made freely available for the firm located in the developing country. This kind of technology transfer may refer to a situation in which the government in the developed country decides to relax the intellectual property rights on green technologies. For instance, by imposing compulsory licensing, the government in the developed country may allow the firm located in the developing country to use the patented process without the consent of the patent owner (the northern firm).

We develop a simple partial equilibrium model to fathom the economics of the international diffusion of climate mitigation technologies in a world with risk of relocation. The model describes the interactions between two regions, the North and the South. In each region, the firms produce the same homogeneous polluting good. Firms may relocate to the other region. The crucial assumption is that the north and the South have implemented environmental regulations. The firms in the North use a cleaner technology. If a firm relocates in the South, it will use the clean technology. The North decides whether it transfers the technology to the South. We assume that adoption is costless, so that if a transfer occurs both firms use the same technology.

We show that first that the technological transfer decreases the incentives to relocate. Indeed, by harmonizing the technology in the two countries, the northern government decreases the incentives for northern firms to relocate to the South since the southern firms are then more competitive. We demonstrate also that relocation decreases the incentive to transfer climate-mitigation technologies. Since the firms which relocate brings its technology in the South, the northern government has less incentives to transfer technology since some firms in the South are already clean.

In the long-term, we analyze the incentives of the North to transfer the clean technology taking into account how it will modify the long-term market structures. We demonstrate that if the transfer decreases the global emissions, the North decides to transfer the technology. Reducing the global emissions is a sufficient condition for the transfer. This result differs from Glachant et al (2016)(10) for whom the reduction of global emissions is a necessary but not sufficient condition. Indeed, they consider both imperfect competition and environmental externality but focus only on the short-run. In our paper, we show that when the government transfers the technology, the domestic market structure is more competitive since it reduces the incentives to relocate.

The paper is structured as follows. Section 2 presents the modeling assumptions and analyzes the scenario with no trade and in the short-run. Section 3 focuses on the long-run market structures and studies the incentives to transfer clean technologies. Section 4 analyzes the cases under which the countries fix the optimal taxes and revise them after the transfer of technology. Section 5 derives the policy implications.

2 The model

2.1 Assumptions

The model describes two countries $k = \{H, F\}$ where H and F respectively denote the home and the foreign country. In each country there are respectively N_H and N_F firms producing a polluting good. Consumers in each country purchase the good and they only consume local goods. Each of the firms $i = \{1, ..., i, ..., N_k\}$ located in the country k produces r_{k_i}. The total production from the home (foreign) country is given by: $R_H = \sum_{i=1}^{i=N_H} r_{H_i}$ ($R_F = \sum_{i=1}^{i=N_F} r_{F_i}$).

The prices are given by the following inverse demand function:

$$p_H = a_H - Q_H; \quad p_F = a_F - Q_F \tag{1}$$

From these function, we get the consumer surplus for each country:

$$CS_H = \int_{p_H}^{a_H} \{a_H - p_H\}\, d\,p_H = \frac{{Q_H}^2}{2}; \quad CS_F = \int_{p_F}^{a_F} \{a_F - p_F\}\, d\,p_F = \frac{{Q_F}^2}{2} \tag{2}$$

Production generates carbon emissions. Formally, one unit of production by the firm located in country k creates μ_k units of emissions. Emissions generate global damage and we assume damage to be linear. The damage in region k is given by the parameter δ_k which can be also interpreted as the environmental willingness to pay in region k. The damage is equal to $\delta_H\,(E_H + E_F)$ in the home country and $\delta_F\,(E_H + E_F)$ in the foreign country where $E_H = \sum_{i=1}^{i=N_H} e_{H_i}$ and $E_F = \sum_{i=1}^{i=N_F} e_{F_i}$.

There are two types of firms, clean ones emitting μ units of emissions by unit produced, and dirty ones emitting μ^0 units of emissions by unit produced, where $\mu^0 > \mu$. In the home country, there are only clean firms ($\mu_H = \mu$) while, in the foreign country, clean and dirty firms coexist ($\mu_F = \{\mu, \mu^0\}$). Let us denote N_{1F}, the dirty foreign firms, and N_{2F} the number of clean foreign firms. The number of firms located in the foreign economy is then: $N_F = N_{1F} + N_{2F}$. This heterogeneity may be interpreted, as home firms that decided to relocate in the foreign economy. In the context of the model, a transfer means that the home country shares its technology with the foreign country so that all firms in the foreign economy use the clean technology μ.

The profit of an individual firm in each country is given by:

$$\pi_H = p_H\,r_H - c_H\,r_H - \sigma_H\,\mu_H\,r_H; \quad \pi_F = p_F\,r_F - c_F\,r_F - \sigma_F\,\mu_F\,r_F \tag{3}$$

Let us denote c_k the production cost in region k and σ_k the carbon tax implemented in the country k. In the foreign country, clean and dirty firms have the same production costs c_F, that can be interpreted as labour costs. In each region, the welfare is defined as the sum of the consumer surplus, the sum of the profit ($\Pi_H = \sum_{i=1}^{i=N_H} \pi_{H_i}$ or $\Pi_F = \sum_{i=1}^{i=N_F} \pi_{F_i}$) and the environmental damage. Therefore:

$$W_H = SC_H + \Pi_H + \sigma_H\, E_H - \delta_H\,(E_H + E_F); \quad W_F = SC_F + \Pi_F + \sigma_F\, E_F - \delta_F\,(E_F + E_H)$$

Let denote π_{Hi} the profit of a firm i producing r_{Hi} and located in the home country. In the home country, each i firm solves the following problem:

$$\max_{r_{Hi}} \pi_{Hi} = p_H\, r_{H_i} - c_H\, r_{H_i} - \sigma_H\, \mu\, r_H \tag{4}$$

Solving this problem for each firm, gives:

$$r_H = \frac{a_H - \mu\,\sigma_H - c_H}{N_H + 1} \tag{5}$$

Let us denote π_{1Fi} the profit of foreign dirty firms, and π_{2Fi} the profit of foreign clean firms. Each firm solves the following problem:

$$\max_{r_{1Fi}} \pi_{1Fi} = p_F\, r_{1F_i} - c_F\, r_{1F_i} - \sigma_F\, \mu^0\, r_{1Fi} \tag{6}$$

$$\max_{r_{2Fi}} \pi_{2Fi} = p_F\, r_{2F_i} - c_F\, r_{2F_i} - \sigma_F\, \mu\, r_{2Fi} \tag{7}$$

Solving this for each firm, gives the following reaction functions:

$$r_{1F} = \frac{a_F - c_F - \mu^0\,\sigma_F - N_{2F}\, r_{2F}}{N_{1F} + 1} \tag{8}$$

$$r_{2F} = \frac{a_F - c_F - \mu\,\sigma_F - N_{1F}\, r_{1F}}{N_{2F} + 1} \tag{9}$$

Using (8) and (9), gives:

$$r_{1F} = \frac{a_F - c_F - ((\mu^0 - \mu)\ N_{2F} + \mu^0)\ \sigma_F}{N_F + 1} \tag{10}$$

$$r_{2F} = \frac{a_F - c_F + ((\mu^0 - \mu)\ N_{1F} - \mu)\ \sigma_F}{N_F + 1} \tag{11}$$

The profits of foreign dirty and clean firms are given, respectively by: $\pi_{1F} = r_{1F}^2$ and $\pi_{2F} = r_{2F}^2$. The consumer surplus is given by $SC_F = \frac{(N_{1F}\, r_{1F} + N_{2F}\, r_{2F})^2}{2}$. Note that a foreign clean firm produces individually more than a foreign dirty firm.

The transfer of technology, increase the quantity produced (and the profit) by foreign firms that were initially dirty, and decreases the quantity produced (and the profit) by the ones that were already clean. The effect of the transfer on the foreign price $p_F = \frac{\left(\mu\, N_{2F} + \mu^0\, N_{1F}\right) \sigma_F + c_F\, N_F + a_F}{N_F + 1}$ of depends on the share of clean firms relatively to the dirty ones. The transfer decreases the price if: $N_{1F} - N_{2F} - 1 > 0$, that is if the number of initially dirty firms is sufficiently large. Under this conditions, the transfer of technology increases the consumer surplus.

As the number of firm increases (increase of N_{1F} or N_{2F}), the quantity produced individually by each type of firms decreases. However, the total production increases and the price decreases: the market becomes more competitive.

2.2 Location choice

We now study the conditions under which a home firm has the incentive to relocate in the foreign country. We assume that the cost of relocation C is constant and the same for all firms. A firm relocates its production in the foreign economy if it gets a higher profit in the foreign country. Said differently, this firm relocates its production if:

$$\pi_{2F}(N_{2F} + 1) - C > \pi_H(N_H) \tag{12}$$

We can show that this inequality can be rewritten as:

$$\left(\frac{a_F - c_F + ((\mu_F - \mu)\, N_{1F} - \mu)\, \sigma_F}{N_{2F} + N_{1F} + 1}\right)^2 - \left(\frac{a_H - c_H - \mu\, \sigma_H}{N_H + 1}\right)^2 > C \tag{13}$$

If the number of relocated firms increases (N_{2F}), the gains of relocation decreases. Indeed, the foreign market is more competitive. Note that since the markets for products in the two countries are independent, for a given firm number of firms (N_H), the home profit $\pi_H(N_H)$ is not affected by the transfer. However, for a given number of firms (N_{1F}, N_{2F}), the profit the home firm receives when it relocates its production, decreases with the transfer. Indeed, a home firm looses its comparative advantage when it relocates if a transfer occurs.

Proposition 1. *The technological transfer decreases the incentives to relocate.*

2.3 Incentives to transfer technology

We study the incentive of the home country to transfer its technology. We assume for the moment that the transfer does not affect the number of firms located in each country. Thus we look at the incentive of the home country to transfer its technology for a given firm's location (N_H, N_F). Since markets are independent, the transfer does not modify the profit and the consumer surplus in the home country. The transfer modifies the profit, and the consumer surplus in the foreign country, and more importantly for the home country it affects the emissions from the foreign country.

First, let us consider the case where there is no relocation ($N_{2F} = 0$). The home country transfers its technology if and only if it decreases the emissions from the foreign country. Initially, the emissions are $E_F = N_F\, \mu^0\, r_{1F}$, thus the transfer only occurs if:

$$E_F(\mu_F = \mu^0) - E_F(\mu_F = \mu) = \frac{(\mu^0 - \mu)\ N_F}{N_F + 1}\ \Big(a_F - c_F - (\mu^0 + \mu)\, \sigma_F\Big) > 0 \tag{14}$$

From $r_F > 0$, $a_F - c_F - \mu^0\, \sigma_F > 0$. Thus (14) is satisfied if μ is relatively low. The transfer of technology does not necessarily decrease the emissions. On the one hand, it increases the production, but on the other hand, it decreases the emission by unit produced.

Let us now consider the incentive of the home country to transfer its technology when in the foreign country dirty and clean firms coexist. We still take for granted the firm's location (N_{1F}, N_{2F}). Since the transfer only affects the foreign emissions, the home country transfers its technology when it decreases foreign emissions, that is if:

$$N_{1F}\,\mu^0\,r_{1F}(\mu_F = \mu^0) + N_{2F}\,\mu\,r_{2F}(\mu_F = \mu^0) > N_{1F}\,\mu\,r_{1F}(\mu_F = \mu) + N_{2F}\,\mu\,r_{2F}(\mu_F = \mu) \tag{15}$$

$$\frac{(\mu^0 - \mu)\;N_{1F}}{N_F + 1}\;\Big(a_F - c_F - (\mu^0 + \mu)\,\sigma_F - \Big(\mu^0 - \mu\Big)\;N_{2F}\,\sigma_F\Big) > 0 \tag{16}$$

When (16) is satisfied, (14) is necessarily satisfied. However, (14) can be satisfied while (16) is not satisfied. It is possible that the home country is willing to transfer its technology, when in the foreign country there are only dirty firms, while it is not willing to transfer, if there are clean and dirty firms. In other word, we we can conclude that:

Proposition 2. *Relocation decreases the incentive to transfer climate-mitigation technologies.*

The transfer increases the quantity produced by firm that were initially dirty and decreases the quantity produced clean firms. The overall production increases. The transfer decreases the emission from the firms clean firms but it has an ambiguous effect on the emissions from initially dirty firms. Indeed, following the transfer, this type of firms become more competitive, and thus they increase their production, but they emit less by unit produced. The initially dirty firms emits less with a transfer if $a_F - c_F - (\mu_F\,N_{2F} + \mu_H + \mu_F)\;\sigma_F > 0$.

3 Incentives to transfer and long-term market structures

We now endogenize the firm's location. We consider a three stage game:

1. The home country decides whether it transfers its technology to the foreign economy.

2. Firms decide whether they relocate.

3. Firms produce and sell the good in the local market for products.

We solve this problem backwards. The third stage is similar to the one defined in section **??**. Let us use the superscript SQ for statu quo (no transfer) and T, for transfer.

Stage 2. Home firms decide whether they relocate their production or not. They act sequentially. We can define the equilibrium location of firms. Indeed, firms have the incentive to relocate their production in the foreign economy, as long at their profit net of the relocation cost is larger than the home profit. The number of firms that relocate their production is given by profit of the last firm that is willing to relocate its production. This firm $\overline{n}$ such as this firm is indifferent between staying in the home economy or relocate in the foreign country:

$$\pi_{2F}(N_{2F}=\overline{n})-C=\pi_H(N_H-\overline{n}+1) \tag{17}$$

$$\left(\frac{a_F-c_F+((\mu_F-\mu_H)\,N_{1F}-\mu_H)\,\sigma_F}{N_{1F}+\overline{n}+1}\right)^2-C=\left(\frac{a_H-c_H-\mu_H\,\sigma_H}{N_H-\overline{n}+2}\right)^2 \tag{18}$$

Let us assume that $C=0$, then $\overline{n}$ is given by:

$$\overline{n}=\frac{(N_H+2)\;(((\mu_H-\mu_F)\;N_{1F}+\mu_H)\;\sigma_F+c_F-a_F)-(N_{1F}+1)\;(\mu_H\,\sigma_H+c_H-a_H)}{\mu_H\,\sigma_H+((\mu_H-\mu_F)\;N_{1F}+\mu_H)\;\sigma_F+c_H+c_F-a_H-a_F}$$

By deriving with respect to μ_F, we obtain:

$$\frac{\partial\,\overline{n}}{\partial\,\mu_F}=\frac{N_{1F}\;(N_H+N_{1F}+3)\;\sigma_F\;(a_H-c_H-\mu_H\,\sigma_H)}{(\mu_H\,\sigma_H+\mu_H\,N_{1F}\,\sigma_F-\mu_F\,N_{1F}\,\sigma_F+\mu_H\,\sigma_F+c_H+c_F-a_H-a_F)^2}>0$$

Corollary 1. *The transfer of technology decreases the number of relocated firms in the long run.*

Stage 1. The home regulator decides whether it transfers its technology to the foreign country.[1]. The home regulator anticipates that the transfer of technology affects the firm's location: the transfer of technology decreases the number of relocated firms. The home regulator wants to maximize its welfare:

$$W_H=SC_H+\Pi_H-\delta_H\;(\mu_H\;(N_H-\overline{n})\;r_H+\mu_F\,N_{1F}\,r_{1F}+\mu_H\,\overline{n}\,r_{2F})+\sigma_H\,\mu_H\;(N_H-\overline{n})\;r_H$$

[1] The welfare is convex in μ_F, thus the regulator chooses to transfer or not its entire technology (corner solutions)

The transfer of technology increases the industry profit in the home country (Π_H). It has no effect on the individual home profit (π_H), but it increases the industry profit by decreasing the relocated firms. Using the same argument, the transfer decreases the product price since it increases the overall home production. As a result, the transfer of technology increases the industry profit and the consumer surplus in the home country.

The global emissions are given by: $E = \mu_H \, (N_H - \overline{n}) \, r_H + \mu_F \, N_{1F} \, r_{1F} + \mu_H \, \overline{n} \, r_{2F}$. Let us now decompose the effect of the transfer on home emissions and foreign emissions (from dirty and clean firms).

The transfer affects the emission in the home economy such as:

$$E_H^{SQ} - E_H^T = \mu \, \left(N_H - \overline{n}^{SQ}\right) r_H^{SQ} - \mu \, \left(N_H - \overline{n}^T\right) r_H^T\right) = \frac{\mu_H \, (a_H - \mu \, \sigma_H - c_H) \, \left(\overline{n}^T - \overline{n}^{SQ}\right)}{(N_H + 1 - \overline{n}^{SQ}) \, (N_H + 1 - \overline{n}^T)} < 0$$

The transfer only affects the home emissions through the number of relocated firms - that is the decrease in the market concentration ($\overline{n}^{SQ} > \overline{n}^T$). The transfer increases the number of firms, and strengthens the competition in the home economy, which decreases the individual production (r_H). The direct effect on the firms' number dominates the indirect effect on production, and the transfer increases the emissions from the home economy.

The transfer affects the emission of initially dirty firms in the foreign economy such as:

$$E_{1F}^{SQ} - E_{1F}^T = \mu^0 \, N_{1F} \, r_{1F}^{SQ} - \mu \, N_{1F} \, r_{1F}^T$$

The transfer has an ambiguous effect on the emissions produced by foreign firms initially using the dirty technology. Indeed, the transfer increases their production through two effects. On the one hand, the transfer decreases the competition in the foreign market (there are less firms), which increases their production. On the other hand, they become more competitive and thus produce more. Finally, even if they produce more, they emit less by unit produced. The transfer may increase or decrease the emissions of foreign firms that are initially dirty.

The transfer affects the emissions of clean firms in the foreign economy such as:

$$E_{2_F}^{SQ} - E_{2F}^{T} = \mu \left(\overline{n}^{SQ}\, r_{2F}^{SQ} - \overline{n}^{T}\ r_{2F}^{T}\right)$$
$$= \frac{\mu \left(\left(\mu^0 - \mu\right)\ N_{1F}\, \sigma_F\, \overline{n}^{SQ}\ \left(\overline{n}^{T} + N_{1F} + 1\right) + \left(N_{1F} + 1\right)\ \left(a_F - \mu\, \sigma_F - c_F\right)\ \left(\overline{n}^{SQ} - \overline{n}^{T}\right)\right)}{\left(\overline{n}^{SQ} + N_{1F} + 1\right)\ \left(\overline{n}^{T} + N_{1F} + 1\right)} > 0$$

The transfer decreases the number of clean firms in the economy, and thus decrease the number of foreign firm which may decrease the emissions. Moreover, the transfer has two opposite effects on the foreign clean firm's production. On the one hand, the transfer decreases the competition in the foreign market (less clean firms), which increases their production. On the other hand, they loose their competitive advantage, and thus produce less. Nevertheless, the overall effect is such that the transfer decreases the emissions from clean firms.

Proposition 3. *The transfer of technology:*

- *increases the emissions from the home economy,*

- *has an ambiguous effect on the emissions from the foreign initially dirty firms.*

- *decreases the emissions from the foreign clean firms.*

- *the transfer has an ambiguous effect on overall emissions*

We can also deduce the following proposition.

Proposition 4. *The reduction of global emissions is a sufficient condition to the technological transfer.*

This result differs from Glachant et al (2016)(10) where the reduction of global emissions is a necessary but not sufficient condition. The intuition is the following. The transfer reduces the relocations and then prevents from a too concentrated market structure in the long-run.

4 Optimal regulation

We now assume that countries non-cooperatively choose the carbon tax maximizing their own welfare. If the home country transfers its technology, then, both countries revise their carbon tax. We study the short-term equilibrium, we assume that the transfer does not affect the firms' location. Before and after the transfer, there are N_H firms in the home economy, N_{1F} dirty firms in the foreign economy, and N_{2F} clean firms in the foreign economy. Before transfer, the welfare functions are given by:

$$W_H = SC_H + \Pi_H - \delta_H \left(\mu\, N_H\, r_H + \mu^0\, N_{1F}\, r_{1F} + \mu\, N_{1F}\, r_{2F}\right) - \sigma_H\, \mu\, N_H\, r_H$$
$$W_F = SC_F + \Pi_{1F} + \Pi_{2F} - \delta_F \left(\mu\, N_H\, r_H + \mu^0\, N_{1F}\, r_{1F} + \mu\, N_{1F}\, r_{2F}\right) - \sigma_F\, (\mu^0\, N_{1F}\, r_{1F} + \mu\, N_{1F}\, r_{2F})$$

The carbon taxes maximizing the welfare functions are given by:

$$\sigma_H = \delta_H - \frac{a_H - \delta_H\, \mu - c_H}{\mu\, N_H}$$
$$\sigma_F = \delta_F - \frac{(a_F - c_F)\, (\mu\, N_{2F} + \mu^0\, N_{1F}) - \delta_F\, \left((\mu^0 - \mu)^2\, N_{1F}\, N_{2F}\, (N_F + 2) + \mu^2\, N_{2F} + \mu^{02}\, N_{1F}\right)}{(\mu\, N_{2F} + \mu^0\, N_{1F})^2}$$

Since there is no trade, the transfer does not affect the consumer surplus nor the profit in the home economy. It only affects the emissions from the foreign economy through a direct effect: a change in the technology and through an indirect effect, a change in the environmental regulation. Thus, the home economy only transfers its technology if it leads to a decrease in foreign emissions.

1. **What is the effect of the transfer on σ_F?**

$$\sigma_F^{SQ} - \sigma_F^{T} = \frac{(\mu^0 - \mu)\; N_{1F}\, \left(\delta_F\, (\mu^0 - \mu)\; \mu\, N_{2F}\, (N_F + 1)^2 + (a_F - c_F)\; (\mu\, N_{2F} + \mu^0\, N_{1F})\right)}{\mu\, N_F\, (\mu\, N_{2F} + \mu^0\, N_{1F})^2}$$

The above equation is positive, the transfer decreases the tax in the foreign economy.

2. **How does the transfer affect the foreign emissions?**

$$r_{1F}^{SQ} - r_{1F}^{T} = -\frac{\mu^0\,\sigma_F^{SQ} - \mu\,\sigma_F^{T} + (\mu^0 - \mu)\;N_{2F}\,\sigma_F^{SQ}}{N_F + 1} \tag{19}$$

Since $\sigma_F^{SQ} > \sigma_F^{T}$, and $\mu^0 > \mu$, $r_{1F}^{SQ} > r_{1F}^{T}$. The transfer increases the production of firms that were initially dirty. By adopting the clean technology, they become more competitive. As a result, the transfer may increase or decrease the emissions from that type of firms.

$$r_{2F}^{SQ} - r_{2F}^{T} = \frac{\mu\left(\sigma_F^{T} - \sigma_F^{SQ}\right) + (\mu^0 - \mu)\;N_{1F}\,\sigma_F^{SQ}}{N_F + 1} \tag{20}$$

The transfer has an ambiguous affect on the production (and the emissions) of clean firms. Indeed, on the one hand, the transfer decreases the emission tax, but on the other hand, this type of firms looses its comparative advantage.

Proposition 5. *If countries implement emission taxes, and revise their regulation after the transfer, then the transfer*

- *decreases the foreign emissions tax,*
- *increases the production of firms that were initially dirty, and has an ambiguous effect on their emissions,*
- *has an ambiguous effect on clean firms' production,*
- *has an ambiguous effect on overall foreign emissions*

3. **Under which conditions the home country is willing to transfer its technology, i.e, when does E_F falls?**

$$\begin{aligned} E_F^{SQ} - E_F^{T} = {} & \frac{(a_F - c_F)\;(\mu^0 - \mu)\;N_{1F}}{N_F + 1} - \frac{\mu^2\,N_F\,(\sigma_F^{SQ} - \sigma_F^{T})}{N_F + 1} \\ & - \frac{(\mu^0 - \mu)\;N_{1F}\;((\mu^0 - \mu)\;N_{2F} + \mu + \mu^0)\;\sigma_F^{SQ}}{N_F + 1} \end{aligned}$$

The emissions falls when $(a_F - c_F)$ is large, when the transfer does not highly decreases the tax, and when the foreign emissions tax is initially relatively low, that is when the foreign country has a low WTP for the environment. By replacing σ_F^T and $\mu_F\,\sigma_F^{SQ}$ by their values, we can properly study the conditions under which the home economy is willing to transfer its technology, the foreign emissions decreases if:

$$
\begin{aligned}
&-\delta_F\left(\left(\mu^0-\mu\right)N_{2F}+\mu^0\right)\left(\left(\mu^0-\mu\right)^2 N_{1F}\,N_{2F}+2\,\mu^2\,N_{2F}+\mu^0\,\mu\,N_{1F}+{\mu^0}^2\,N_{1F}\right) \qquad (21)\\
&+\left(a_F-c_F\right)\mu^0\left(\mu\,N_{2F}+\mu^0\,N_{1F}\right)>0
\end{aligned}
$$

Let us now determine how the relocation affect the transfer decisions. Assume that there is no relocation, that is $N_{2F}=0$, then (21) becomes:

$$
{\mu^0}^2\,N_{1F}\left(a_F-c_F-\delta_F\,\mu-\delta_F\,\mu^0\right) \qquad (22)
$$

(21) may decrease with N_{2F}, in other words, the firm's relocation may prevent the transfer. As the number of relocated firms increases the home's regulator has less incentive to transfer its technology. We still have to check if it is possible to have (21) increasing with N_{2F}, that is if relocation may promote the transfer

Proposition 6. *Under emissions taxes,*

- *The home economy is willing to transfer its technology when:*
  - *the WTP for the environment in the foreign economy is low,*
  - *when (a_F-c_F) is large - Intuition?*
  - *what about μ, N_{2F}, μ^0 and N_{1F}?*
- *The home firms' relocation may prevent the transfer*

4. **The location choice:**

Under emissions taxes, a firm relocates its production if (12) is satisfied, that is if:

$$
\begin{aligned}
&\left(\frac{\left(a_F-c_F\right)\mu_F}{\mu_H\left(N_{2F}+1\right)+\mu_F\,N_{1F}}-\frac{\delta_F\left(\Delta\mu\left(N_{2F}+1\right)+\mu_F\right)\left(\Delta\mu\,N_{1F}\left(\Delta\mu\,N_{2F}+2\,\mu_F\right)+{\mu_H}^2\left(N_F+1\right)\right)}{\left(\mu_H\left(N_{2F}+1\right)+\mu_F\,N_{1F}\right)^2}\right)^2\\
&-\left(\frac{a_H-c_H-\delta_H\,\mu_H}{N_H}\right)^2>C
\end{aligned}
$$

where $\Delta\mu = \mu_F - \mu_H$.

From proposition 5, the transfer has an ambiguous effect on foreign clean firms' production. Thus, it has an ambiguous effect on how the transfer affects the relocation incentives. The transfer prevent the home's firm relocation if (20) holds, that is if:

$$\delta_F \left(\left(2\,\mu^2\,N_{2F} + {\mu^0}^2\,N_{1F}\right)\,N_F - \mu\,N_{2F}\,\left(\mu^0\,\left(N_{2F} + \mu^0\,N_{1F}\right) - \Delta\mu\right) + \Delta\mu^2\,N_{1F}\,N_{2F}\,N_F\right)$$
$$-\left(a_F - c_F\right)\,\left(\mu\,N_{2F} + \mu^0\,N_{1F}\right) > 0$$

From, this we can deduce the following proposition:

Proposition 7. *If countries implement emissions taxes, and revise their environmental regulation following the transfer, the transfer of clean technology has an ambiguous effect on the home's firm incentive to relocate their production. The transfer favors lenient environmental regulation in the foreign economy, but it removes the home's firm comparative advantage.*

5 Trade in polluting goods

Assume that there is trade. Let us denote r_{HH} and r_{HF}, the production of a home firm, respectively, sold at home and sold in the foreign economy. Let us also denote r_{1FH} and r_{1FF} (r_{2FH} and r_{2FF}), the production of a foreign initially-dirty (clean) firms, sold at home and sold in the foreign economy. To sell the good abroad, firms bear a transportation cost t. The price of the polluting good in region k is given by $p_k = a_k - Q_k$, so that:

$$p_H = a_H - N_H\,r_{HH} - N_{2F}\,r_{2FH} - N_{1F}\,r_{1FH} \tag{23}$$

$$p_F = a_F - N_H\,r_{HF} - N_{2F}\,r_{2FF} - N_{1F}\,r_{1FF} \tag{24}$$

Without transfer, the profits are then given by:

$$\pi_H = p_H\, r_{HH} + p_F\, r_{HF} - c_H\, r_{HH} - (c_H + t)\, r_{HF} - \sigma_H\, \mu\, (r_{HH} + r_{HF}) \tag{25}$$

$$\pi_{1F} = p_H\, r_{1FH} + p_F\, r_{1FF} - c_F\, r_{1FF} - (c_F + t)\, r_{1FH} - \sigma_F\, \mu^0\, (r_{1FH} + r_{1FF}) \tag{26}$$

$$\pi_{2F} = p_H\, r_{2FH} + p_F\, r_{2FF} - c_F\, r_{2FF} - (c_F + t)\, r_{2FH} - \sigma_F\, \mu\, (r_{2FH} + r_{2FF}) \tag{27}$$

By solving the problem, we obtain the following productions:

$$r_{HH} = \frac{N_F\, t - \mu\ (N_F + 1)\ \sigma_H + (\mu\, N_{2F} + \mu^0\, N_{1F})\ \sigma_F + (cf - ch)\ N_F + a_H - c_H}{N_H + N_F + 1}$$
$$r_{HF} = \frac{-\,(N_F + 1)\ t - \mu\ (N_F + 1)\ \sigma_H + (\mu\, N_{2F} + \mu^0\, N_{1F})\ \sigma_F + (c_F - c_H)\ N_F + a_F - c_H}{N_H + N_F + 1}$$
$$r_{1FF} = \frac{N_H\, t + \mu\, N_H\, \sigma_H - (\mu^0\ (N_H + 1) + (\mu^0 - \mu)\ N_{2F})\ \sigma_F + (c_H - c_F)\ N_H + a_F - c_F}{N_H + N_F + 1}$$
$$r_{1FH} = \frac{-\,(N_H + 1)\ t - \mu\, N_H\, \sigma_H + (\mu^0\ (N_H + 1) + (\mu^0 - \mu)\ N_{2F})\ \sigma_F + (c_H - c_F)\ N_H + a_H - c_F}{N_H + N_F + 1}$$
$$r_{2FF} = \frac{N_H\, t + \mu\, N_H\, \sigma_H + ((\mu^0 - \mu)\ N_{1F} - \mu\ (N_H + 1))\ \sigma_F + (c_H - c_F)\ N_H + a_F - c_F}{N_H + N_F + 1}$$
$$r_{2FH} = \frac{-\,(N_H + 1)\ t + \mu\, N_H\, \sigma_H + ((\mu^0 - \mu)\ N_{1F} - \mu\ (N_H + 1))\ \sigma_F + (c_H - c_F)\ N_H + a_H - c_F}{N_H + N_F + 1}$$

The transfer of technology increases the production of the foreign initially-dirty firms (r_{1FH} and r_{1FF}), and decreases the production of the other firms. The effect on the polluting good price depends on the firm's number, the transfer decreases the price in the home economies and in the foreign economies if: $2\, N_{1F} - N_H - N_{2F} - 1 > 0$.

A home firm relocates its production if:

$$\pi_{2FH}(N_{2F} + 1, N_H - 1) + \pi_{2FF}(N_{2F} + 1, N_H - 1) - C > \pi_{HF} + \pi_{HF} \tag{28}$$

If $\mu\, (\sigma_H - \sigma_F) + c_H - c_F > 0$, which is a reasonable assumption, the transfer of technology prevents the home firms' relocation.

We still need to define how the relocation affects the transfer decisions.

6 Imitation and spillovers

Let assume that foreign firms may imitate the technology used by firms which have relocated their production to their country. Indeed, it is easier to copy and imitate a firm located in the foreign economy than a firm located in the home economy for several reasons; firms may have the same suppliers, they may hire employees working previously in the relocated firm, less stringent property rights in the foreign economy than in home economy.

We consider that the emission intensity in the foreign country decreases with relocation. We assume that the more home firms relocate, the more the foreign firms imitate, the higher spillovers are. Let consider that the emission intensity in the foreign country is a logistic function, decreasing with the number of clean firms in the foreign economy and whose asymptotes are μ^0 and μ. Let denote this function by $\mu(N_{2F})$.

Taking into account the previous assumptions, we can express the productions in the foreign economy of clean and dirties firms.

$$r_{1F} = \frac{a_F - c_F - ((\mu(N_{2F}) - \mu)\ N_{2F} + \mu(N_{2F}))\ \sigma_F}{N_F + 1} \tag{29}$$

$$r_{2F} = \frac{a_F - c_F + ((\mu(N_{2F}) - \mu)\ N_{1F} - \mu)\ \sigma_F}{N_F + 1} \tag{30}$$

The emissions in the foreign country are given by $N_{1F}\mu(N_{2F})r_{1F} + N_{2F}\mu r_{2F}$. The intuition seems to be the following. Relocation increases the reduction of the total emissions and then reduces the intuition to transfer the technology.

7 Market for permits

If the countries implement market for permits instead of taxes, two additional effects are at stake. For exogenous pollution cap, relocation increases demand for permits in the foreign economy and reduces the demand for permits in the home economy. Thus, relocation affects the equilibrium permit prices. While permit price increases in the foreign economy, it decreases in the home economy. Transfer of technology also affects the permit price in the foreign country and then the incentives to relocate.

8 Conclusion and policy implications

The transfer of technologies may be used to prevent firms from relocating.

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Appendices

A Market for products

Home economy: If we denote r_{Hj}, the production of the $(N_H - 1)$ other firms, (4) becomes:

$$\pi_{Hi} = (a_H - (N_H - 1)\, r_{Hj} - r_{Hi})\, r_{Hi} - c_H\, r_{Hi} - \sigma_H\, \mu_H\, r_{Hi}$$
$$\frac{\partial \pi_{Hi}}{\partial r_{Hi}} = a_H - (N_H - 1)\, r_{Hj} - 2\, r_{Hi} - c_H - \sigma_H\, \mu_H = 0$$

Firms are symmetric, $r_{Hj} = r_{Hi} = r_H$ and the home firm's production is given by (5).

Foreign economy: If we denote r_{1Fj}, the production of the $(N_{1F} - 1)$ other initially-dirty firms and $N_{2F}\, r_{2F}$ the total production of clean firms, (6) can be rewritten as:

$$\pi_{1Fi} = (a_F - (N_{1F} - 1)\, r_{1Fj} - r_{1Fi} - N_{2F}\, r_{2F})\, r_{1F_i} - c_F\, r_{1F_i} - \sigma_F\, \mu_F\, r_{1Fi}$$
$$\frac{\partial \pi_{1Fi}}{\partial r_{1Fi}} = a_F - (N_{1F} - 1)\, r_{1Fj} - N_{2F}\, r_{2F} - 2\, r_{1Fi} - c_F - \sigma_F\, \mu_F$$

Since firm are symmetric $r_{1Fj} = r_{1Fi} = r_{1F}$ and reaction function of an initially-dirty firm is given by (8).

If we denote r_{2Fj}, the production of the $(N_{2F}-1)$ other clean firms and $N_{1F}\, r_{1F}$ the total production of the initially-dirty firms, (7) can be rewritten as:

$$\pi_{2Fi} = (a_F - (N_{2F} - 1)\, r_{2Fj} - r_{2Fi} - N_{1F}\, r_{1F})\, r_{2F_i} - c_F\, r_{2F_i} - \sigma_F\, \mu_H\, r_{2Fi}$$
$$\frac{\partial \pi_{2Fi}}{\partial r_{2Fi}} = a_F - (N_{2F} - 1)\, r_{2Fj} - N_{1F}\, r_{1F} - 2\, r_{2Fi} - c_F - \sigma_F\, \mu_H$$

Since firm are symmetric $r_{2Fj} = r_{2Fi} = r_{2F}$, and reaction function from clean firms is given by (9).