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The incentives to North-South transfer of climate-mitigation technologies with trade in polluting goods

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Abstract

The need to transfer climate mitigation technologies towards the developing world has been acknowledged since the beginning of climate negotiations. Little progress has however been made as shown by Article 10 of the Paris Agreement. One reason is that these technologies could become vital assets to compete on global markets. This paper presents a partial equilibrium model with two regions, the North and the South, and imperfect competition in the international polluting goods market to analyze the North's incentives to accept technology transfer. Results crucially depend on the existence of environmental cooperation. When both northern and southern governments set emission quotas non-cooperatively, inducing fewer global emissions is a necessary, but not sufficient condition for the North to accept the transfer. In contrast, when governments set quotas cooperatively, the North never accepts the transfer because it only leads to a partial relocation of pollutant goods production to the South. We derive the implications for the global regulation of climate change.

JEL codes: D43; F18; Q5.
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1 Introduction

In Article 2 of the Paris Agreement adopted in December 2015 within the framework of the United Nations Framework Convention on Climate Change (UNFCCC), the reference

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target is to hold "the global average temperature to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees above pre-industrial levels". All observers and players are aware that the two degrees target is not achievable without a massive deployment of advanced climate mitigation technologies in the world economy. One difficulty is that these technologies have been mostly developed in industrialized countries, while they are urgently needed in emerging economies where the bulk of emission increases is expected in the future. Dechezleprêtre et al. (2011) show that two thirds of the technologies patented between 2000 and 2005 were developed in only three industrialized countries, namely the USA, Germany and Japan, while more than 75% of growth in CO2 emissions until 2050 is expected to come from the developing world, with India and China alone accounting for 50%. Accordingly, fostering North-South transfer of climate mitigation technologies is logically viewed as an essential element of the global solution to the climate change problem. In practice, this could be achieved through sector-specific training programs, technological cooperation projects, pilot plants involving technology leaders and laggards... Another hotly debated solution is to differentiate intellectual property rights for specific green technologies, by introducing patent term extension, compulsory licensing or voluntary patent pools (see Hoekman et al., 2005; Ockwell et al., 2008; Maskus, 2010, for a discussion of the available solutions).

The importance of international technology transfer towards the developing world has been acknowledged since the beginning of climate negotiations. In particular, Article 4 of the United Framework Convention on Climate Change (UNFCCC) adopted in 1992 includes an explicit commitment to promote international technology diffusion. Since then, negotiations over this issue have however made little progress (Technology Executive Committee, 2011; Glachant and

Dechezleprêtre, 2015). A so-called Technology Mechanism was admittedly established at the 16th session of the COP in Cancun in December 2010 in order to "facilitate the implementation of enhanced action on technology development and transfer in order to support action on mitigation and adaptation to climate change". But, in practice, this Mechanism is a modest coordination body called on to design future solutions that remain to be developed. The 2015 Paris Agreement has not taken any significant step forwards.

It is true that promoting international technology transfer involves considerable policy and economic challenges. On the one hand, developing countries see technology transfer as a costly process that should partially be covered by developed nations. On the other hand, governments in developed countries fear that ambitious technology transfer policies might deprive local innovative firms of vital intellectual assets. This concern finds a particular echo in a context where political leaders frequently push forward the concept of green growth as a means to boost the international competitiveness of their economy. For these reasons, negotiations have so far revolved around the financing of technology transfer and the role of intellectual property rights (IPRs), which some countries view as a barrier to technology diffusion (Abdel-Latif, 2015).

In this paper, we develop a simple partial equilibrium model to provide a better understanding of the economics of the international diffusion of climate mitigation technologies in a world with trade and the implications for the global regulation of greenhouse gas emissions (GHG). The model describes the interactions between two regions, the North and the South. In each region, a firm produces the same homogeneous polluting good, which is traded in an international imperfectly competitive market. The crucial assumption is that the northern firm initially owns a greener production technology than its southern competitor, that is, a technology that emits fewer GHG per unit of production. A technology transfer will then be equivalent to that technology being adopted by the firm located in the South. In both regions, consumers purchase the good and victims suffer from the environmental damage generated by global emissions. A welfare maximizing government also regulates the domestic firm by setting a cap on emissions. Under these assumptions, the results will be driven by the existence of two market imperfections: the environmental externality and the under-production problem induced by imperfect competition in the polluting good market.

We use this set-up to identify the governments' incentives to transfer the green technology under different scenarios. The analysis focuses on the northern government; under our assumptions, the South is indeed structurally favorable to gaining access to improved technologies. In the first scenario, the two governments set the emission quotas non-cooperatively. In this case, we show that inducing fewer emissions is a necessary, but not sufficient condition for the North to accept the transfer. The difference between North and South environmental willingness to pay should also be high with the North attributing a high value to the emissions cuts made in the South, which are significant because the initial emission quota is lax. The demand in the South for the polluting good should also be high: in that case, the cap before transfer is lenient in the South as the local government is more concerned by under-production harming its consumers than by pollution.

In the second scenario, the regions cooperate to set caps. In this case, we show that the northern government never accepts sharing technology. The level of emissions and consumption is the same with and without transfer and production locates where the best technology is available: in the North before transfer, in both regions after transfer. The only contribution of the transfer is thus to shift production (and thus profits) from the North to the South. From a normative perspective, the transfer is welfare neutral, it only has distributional consequences, which are negative (positive, resp.) for the North (South, resp.).

This analysis has interesting policy implications. Assuming that the Paris Agreement marks a shift to a new international regime with environmental cooperation between the North and the South, the model predicts a limited propensity of governments from industrialized countries to promote technology transfer in sectors with international competition in the future. Article 10 of the Paris Agreement – which includes vague commitments on technology – lends support to this view. From a normative point of view, this may not be so problematic. As suggested by the model, when there is international trade and environmental cooperation, technology transfer is less critical as production tends to locate where the best technologies are available.[1] In a nutshell, technology transfer should be primarily viewed as a distributional issue to be included in the discussions about the ways to compensate the South for the historic responsibilities of the industrialized world.

There is now a well-established literature on the role of technology transfer in international climate policy (see Popp, 2011, for a survey) [2]. A first branch includes empirical studies which look at the geography and trends of the international diffusion of climate mitigation technologies. Using patent statistics over 2000-2005, Dechezleprêtre et al. (2011) show that technologies were starting to flow in the developing world 10-15 years ago as bilateral transfers between OECD and non OECD represented 22% of the total. One possible reason for these transfers was the Clean Development Mechanism, a carbon trading scheme established under the Kyoto Protocol in 1997 whereby industrialized countries could develop or finance

[1] A further external argument is suggested by Glachant and Dechezleprêtre (2015) who use recent data on the trade in low carbon equipment goods and foreign investments to show that technology transfer already takes place through market channels.

[2] The literature on the interactions between R&D and climate negotiations is even more developed Barrett (e.g., 2006), but ignored in this literature review as the incentives are very different.

projects that reduce greenhouse gas (GHG) emissions in non-Annex 1 countries in exchange for emission reduction credits. This argument is supported by a number of empirical contributions which measure the size of the transfer by the Clean Development Mechanism (see for example Haites et al., 2006; Dechezleprêtre et al., 2008). Another branch of the literature includes works which assess the impact of technology transfer on different economic variables (e.g. GDP, emissions) with Integrated Assessment Models (for instance, Yang and Nordhaus, 2006).

Our paper is more closely related to theoretical studies that look at countries' incentives for technology transfer. The pioneering work by Stranlund (1996) examines a context where the countries do not cooperate in abatement (i.e., as in section 3 of the present paper). He assumes no trade and results are thus centrally driven by the impact of technology transfer on emissions. This leads to an optimistic message on the potential of technology transfer.[3] In contrast, a central feature of our setting is that technologies are transferred to competitors, which obviously reduces the propensity of firms and governments to share their technologies.

More recent studies assume international trade, but not in the market of the polluting good. Stephan and Müller-Fürstenberger (2015) analyze the transfer of energy saving technologies. In their model, country incentives are centrally driven by international trade in carbon energy. As technology transfer reduces energy consumption in the recipient country, the energy price in the international market shrinks. The welfare consequences for the technology provider or recipient then depend on whether they import or export energy. The insight is very similar in Helm and Pichler (2011) except that they assume international trade in a global carbon market.

[3]A related paper is Lee (2001) who includes an analysis of income transfer.

The paper is structured as follows. Section 2 presents the modeling assumptions. Section 3 analyzes the scenario with no cooperative environmental regulations. Section 4 focuses on the case where the transfer takes place in an international institutional regime with environmental cooperation. Section 5 derives the policy implications.

2 The model

2.1 Assumptions

The model describes two regions, the North and the South, denoted respectively by $i = \{N, S\}$. In each region, consumers purchase the same homogeneous good in the global market. We assume the same linear demand function in the two regions: $q_i = a_i - \frac{p}{2}$ where q_i is the quantity of good purchased by consumers from region i and p, the product price which is the same in both regions (we assume zero transportation cost). Accordingly, consumer surplus in region i is:

$$CS_i = \int_p^{2\,a_i} \{a_i - \frac{p}{2}\}.\, dp = \frac{(2\,a_i - p)^2}{4} \tag{1}$$

The inverse demand function in the global market is given by:

$$p(q_N, q_S) = a_N + a_S - q_N - q_S. \tag{2}$$

The good is produced by two firms, one in each region, which compete à la Cournot. Production generates carbon emissions. Formally, one unit of production by the firm located in region i creates μ_i units of emissions. The firm's total emissions are thus equal to $e_i = \mu_i\, r_i$

where r_i is the quantity produced by the firm located in region i. These emissions generate global damage. The damage in region i is given by the parameter λ_i which can be interpreted as the environmental willingness to pay in region i. The damage is equal to $\lambda_N (e_N + e_S)$ in the North and $\lambda_S (e_N + e_S)$ in the South. We assume that $\lambda_N > \lambda_S$.

A crucial assumption is that the environmental technology used in the North is initially more advanced than in the South: $\mu_N = \mu$ and $\mu_S = \mu^0$ with $\mu < \mu^0$. In the context of the model, a transfer means that the North shares its technology with the South so that $\mu_S = \mu$.[4,5] Note that this representation is fully compatible with the existence of non-intentional transfer through cross-country knowledge spillovers. The parameter μ^0 should then be viewed as the technology level in the South after internalization of spillovers by the southern firm. The fact that there remains a gap between μ and μ^0 captures the fact that the exploitation of spillovers does not allow the northern technology to be replicated perfectly.

For ease of presentation, we assume that production costs are zero. Formally, firm i's profit is $\pi_i = p(q_N, q_S)\, r_i$ where r_i is the output and $p(q_N, q_S)$ the inverse demand function (2). Introducing positive production costs would not qualitatively alter the results.

Under these assumptions, the only option to cut emissions is to reduce production and the abatement cost amounts to a foregone profit. This is clearly restrictive, but it allows a very transparent linkage between the product market and firms' environmental behavior to be created. At the end of the analysis, we will discuss how results change if one adopts the alternative polar (and popular) assumption that the level of abatement is independent of the quantity produced.

[4]The assumption here is that the technology cannot be split in the sense that the northern technology is entirely transferred or not. Allowing for interior solutions would not qualitatively alter the results.

[5]Assuming no trade, the analysis of technology transfer would be trivial. In this case, the only issue is its impact on emissions in the South and the northern government always accept transfer if it reduces these emissions.

In each region, a government cares about consumer surplus, profit and environmental damage. It thus seeks to maximize:

$$W_i = SC_i + \pi_i - \lambda_i \left(e_N + e_S\right)$$

Each government regulates the emissions of the firm located in its economy. More specifically, it sets a quota defining a maximal level of emissions. As the firm is unique in each region, this policy is strictly equivalent to a carbon market in which the quantity of permits is equal to the quota; let E_i denote the quota in region i.[6] In the first sections of the paper, we will assume that the quota is chosen unilaterally by each government. In the last sections, we will investigate a scenario where they coordinate their policies through an international climate agreement.

2.2 Status quo

We now characterize the status quo scenario in which each region sets its climate policy unilaterally – without taking into account the environmental damage generated abroad – and there is no technology transfer .

Firm i solves

$$\max_{r_i} \pi_i = p(q_N, q_S)\, r_i \quad \text{subject to} \quad \mu_i\, r_i \leq E_i$$

In what follows in this paper, we will focus on the interesting case where both firms are

[6] In the real world, energy intensive industries that operate on international markets are increasingly regulated by carbon markets (such markets exist in the European Union, in several important US States, in China...).

constrained by the regulation so that: $r_i\,\mu_i = E_i$. Assuming a binding regulation, production in one region then depends on the quota implemented and the emission intensity in this region. We will establish below the precise conditions on the parameters for the regulation constraint to bind.

Plugging quantities in (2), we obtain the product price:

$$p = a_S + a_N - \frac{E_N\,\mu^0 + E_S\,\mu}{\mu\,\mu^0}$$

We see that the more stringent the cap in a region, the higher the product price because less pollution induces less production. Profits in the North and in the South are respectively given by:

$$\pi_N = \frac{E_N}{\mu}\,\left(a_S + a_N - \frac{E_N\,\mu^0 + E_S\,\mu}{\mu\,\mu^0}\right) \tag{3}$$

$$\pi_S = \frac{E_S}{\mu^0}\,\left(a_S + a_N - \frac{E_N\,\mu^0 + E_S\,\mu}{\mu\,\mu^0}\right) \tag{4}$$

Unsurprisingly, the emission quota in one region reduces profits at home and increases profits abroad. Plugging the product price in (1) yields the consumer surplus:

$$CS_N = \frac{1}{4}\left(a_N - a_S + \frac{E_N\,\mu^0 + E_S\,\mu}{\mu\,\mu^0}\right)^2 \tag{5}$$

$$CS_S = \frac{1}{4}\left(a_S - a_N + \frac{E_N\,\mu^0 + E_S\,\mu}{\mu\,\mu^0}\right)^2 \tag{6}$$

which decreases here with both caps as total production falls while the price increases.

To sum up, introducing a cap damages the domestic firm's profit and exacerbates the under-production problem (as production is even less than the un-constrained duopoly quantities), which hurts domestic consumers. But the benefit is to decrease pollution. The optimal cap thus trades off economic benefits (profits and consumer surplus) and environmental benefits. To select this cap, the two governments non-cooperatively solve the following programs.

$$\max_{E_N} W_N(E_N, E_S) = CS_N + \pi_N - \lambda_N(E_N + E_S)$$

$$\max_{E_S} W_S(E_S, E_N) = CS_S + \pi_S - \lambda_S(E_N + E_S)$$

Substituting (3) and (5) and (6) in W_N and differentiating, we get:

$$\frac{\partial W_N}{\partial E_N} = \frac{1}{2\,\mu^2\,\mu^0}\left(a_S\,\mu\,\mu^0 + 3\,a_N\,\mu\,\mu^0 - E_N\,\mu^0 - E_S\,\mu\right) - \frac{E_N}{\mu^2} - \lambda_N$$

This derivative shows that the two pollution caps are strategic complements – the North cap in the North decreases with the South cap – which creates free riding. This property is driven by two factors: environmental externality and the under-production problem in the product market. When the pollution cap in the South is low, the North suffers from limited damages, giving room to increase emissions at home. The southern production is also low, which increases incentives to raise local production.

Solving the two welfare maximization programs gives the following closed-form solution:

Lemma 1. *In the status quo, each government chooses the following emission caps:*

$$E_N^0 = \frac{\mu}{4}\left(\lambda_S\,\mu^0 - 3\,\lambda_N\,\mu + 4\,a_N\right); \quad E_S^0 = \frac{\mu^0}{4}\left(\lambda_N\,\mu - 3\,\lambda_S\,\mu^0 + 4\,a_S\right)$$

These caps mitigate two market imperfections, which have opposite impacts on production and pollution. Reducing environmental damage requires emissions and thus production to be curbed, but mitigating the under-production problem conversely requires production to be increased. Similarly, if the market size is large (a high a_N or a high a_S), under-production is the most serious concern and the regulator sets a high pollution cap.

It is also possible to see how emission intensity in the South will influence E_N^0 as transferring technology basically means decreasing μ^0. When emission intensity decreases in the South, production in this region becomes higher. The best reply of the North is then to both produce and pollute less. Technology transfer thus has contrasted impacts on social welfare in the North as it mitigates the externality problem, but reinforces the under-production problem.

We finish the status quo analysis by specifying more precisely the assumption made initially to make sure that regulation is binding in the two regions and that the level of consumption is strictly positive in all equilibria. That is, the level of production in the absence of an emissions cap is higher than the level when E_N^0 and E_S^0 are implemented and $q_i = a_i - \frac{p^1}{2}$ is positive. Simple calculations show that these conditions impose the following assumption on the parameters:

Assumption 1.

$$\lambda_S\,\mu^0 + \lambda_N\,\mu \leq 4\,a_N \leq \lambda_S\mu^0 + 5\,\lambda_N\,\mu$$

$$\lambda_S\,\mu^0 + \lambda_N\,\mu \leq 4\,a_S \leq \lambda_N\mu + 5\,\lambda_S\,\mu^0$$

3 Technology transfer without environmental cooperation

We now consider a scenario in which the North transfers its technology while both regions continue to set their climate policies non-cooperatively. The analysis is simple as we just need to substitute μ^0 by μ in the status quo equations to characterize the post-transfer equilibrium.

Before transfer, the two firms jointly produce

$$Q_0 = \frac{E_N^0}{\mu} + \frac{E_N^0}{\mu^0} = a_N + a_S - \frac{1}{2}\left(\lambda_N \mu + \lambda_S \mu^0\right)$$

which decreases with μ^0. A first important result is thus that the transfer increases total production because better technologies allow the constraint on production to be mitigated.

We now show that the transfer has an ambiguous impact on carbon emissions as it reduces emission intensity, but increases production. Adapting Lemma (1), we first characterize the quotas in the post-transfer equilibrium:

Lemma 2. *After transfer, the caps set in the two regions without cooperation are given by:* $E_N^1 = \frac{\mu}{4}\,(\lambda_S\,\mu - 3\,\lambda_N\,\mu + 4\,a_N)$ *and* $E_S^1 = \frac{\mu}{4}\,(\lambda_N\,\mu - 3\,\lambda_S\,\mu + 4\,a_S)$*.*

We can now compare the level of the quotas with and without transfer given by lemmas 1 and 2. We need however to revise Assumption 1 to have binding regulation and non-negative consumption in both scenarios. To derive these conditions, we simply need to replace μ^0 by μ in Assumption 1 and compare the two sets of equations. This leads to:

Assumption 2.

$$\lambda_S\,\mu + \lambda_N\,\mu \le 4\,a_N \le \lambda_S\mu + 5\,\lambda_N\,\mu$$

$$\lambda_S\,\mu + \lambda_N\,\mu \le 4\,a_S \le \lambda_N\mu + 5\,\lambda_S\,\mu$$

The differences in the caps before and after transfer in both regions are then:

$$E_N^0 - E_N^1 = \frac{(\mu^0-\mu)\lambda_S\mu}{4}$$
$$E_S^0 - E_S^1 = \frac{(\mu^0-\mu)(4\,a_S + \lambda_N\mu - 3\,\lambda_S(\mu^0+\mu))}{4}$$

Emissions fall in the North as the firm does not change the technology and produces less. In contrast, the sign is ambiguous in the South[7]. The sign of the variation of total emissions before and after transfer is then the same as that of:

$$-4\,a_S - \lambda_N\,\mu + 2\,\lambda_S\,\mu + 3\,\lambda_S\mu^0 \tag{7}$$

The sign of this expression is ambiguous[8]. This is driven by the above-mentioned trade-off between the externality problem and the under-production problem. As an illustration, emissions decrease when demand is high enough in the South (i.e., a high a_S). In that case, consumer surplus has more weight in the regulator's objective function. The cap thus tends to be lenient in the status quo because the regulator is primarily concerned with under-production. By reducing constraints on the level of production, the transfer mitigates this problem, leaving space to reduce the cap. In contrast, strong environmental preferences in

[7] For instance, it is positive if $\lambda_S = 0$, but negative if a_S reaches its lowest value: $a_S = \lambda_S\,\mu + \lambda_N\,\mu$ and $\lambda_N = \lambda_S$.

[8] For instance, it is positive if $\lambda_S = 0$, but negative if $a_S = \lambda_S\,\mu + \lambda_N\,\mu$ and $\lambda_N = 0$.

the South (a high λ_S) may have a detrimental impact on emissions: The cap was already strict in the South before transfer and a better technology allows the regulator to relax the tight constraints imposed on production in the status quo.

To sum up, we have:

Proposition 1. *The transfer of technology has an ambiguous environmental impact. It can increase global emissions when demand in the South is low (a low a_S), when the environmental willingness to pay is large in the south (a high λ_S), and/or when the initial technology used in the South is relatively inefficient (a large μ^0).*

We now analyze the impact of the transfer on profits and consumer surplus. The product price is initially $p^0 = \frac{1}{2}\left(\lambda_N \, \mu + \lambda_S \, \mu^0\right)$. It will decrease with the transfer (as p^0 is increasing with μ^0) because total production becomes higher. An immediate consequence is that the firm located in the North makes less profit as it produces less [9]. This result is expected, but nevertheless important: the northern firm is never willing to transfer its technology (for free) to its competitor. Transfer can thus only be induced by public intervention. In contrast, the impact on profits in the South is always positive despite the lower product price. The southern firm's profit before transfer is indeed equal to:

$$\pi_S^0 = \frac{1}{8}\left(\lambda_N \, \mu + \lambda_S \, \mu^0\right)\left(4 \, a_S + \lambda_N \, \mu - 3 \, \lambda_S \, \mu^0\right)$$

which is decreasing with μ^0. If available, the southern firm will thus spontaneously adopt the technology.

Greater production and a lower price also imply a higher surplus for consumers in the two

[9] Its status quo production is $E_N^0/\mu = \frac{1}{4}\left(\lambda_S \, \mu^0 - 3 \, \lambda_N \, \mu + 4 \, a_N\right)$ which increases with μ^0.

regions (see equation (1)). We summarize these findings in a new proposition.

Proposition 2. *The transfer of technology increases profit in the South, but decreases it in the North. In both regions, consumers are better off.*

As the technology owner has no incentive to transfer the technology without public intervention, we now examine whether the northern government is willing to force the firm to do so or to provide the firm with the necessary incentives. The North will trigger a transfer if it increases its welfare compared with the status quo:

$$W_N\left(E_N^1, E_S^1 \mid \mu_S = \mu\right) > W_N\left(E_N^0, E_S^0 \mid\ \mu_S = \mu^0\right)$$

Simple calculations show that this decision rule is equivalent to:

$$4\,\lambda_N\,(\lambda_N\,\mu + 4\,a_S) - 6\,\lambda_N\,\lambda_S\,\left(\mu + 2\,\mu^0\right) - 3\,{\lambda_S}^2\,\left(\mu + \mu^0\right) > 0 \tag{8}$$

The study of this inequality in the Appendix yields the following results.

Proposition 3.

(i) When the regions do not cooperate to set pollution caps, the North never shares its technology if the transfer increases overall emissions.

(ii) Otherwise, it can accept the transfer if the environmental willingness to pay is low (high) in the South (North), and if the market size in the South is large.

(iii) The southern government and its firm always accept the transfer.

Proof. See in Appendix. □

Result (i) is crucial since it means that the main motivation for transferring technology is to decrease overall emissions. Recall that, from the North's perspective, a transfer always reduces profit and increases the consumer surplus. The result thus states that the positive impact of the transfer on consumers never compensates the negative impact on profits and the increase in environmental damage.

However, the reduction in emissions is a necessary but not sufficient condition for the transfer as there is ambiguity when emissions are reduced. In this case, a large market in the South means greater emphasis on increasing production in this region (to increase the consumer surplus) and less on pollution. In this context, transferring the technology is valued by the North as it counterbalances in favour of greater abatement. The impact of the damage parameters is driven by the same logic; the North transfers its technology to limit emissions when it values the environment highly. Moreover, the North is more willing to transfer its technology when the South places a low value on the environment (low λ_S) since the latter implements a too lenient climate policy without transfer. [10]

The third result that the South always accepts the transfer is straightforward, but worth mentioning. When emissions fall, this reduces environmental costs in the South, pleases its consumers and the domestic firm.

[10] If we consider that the level of abatement is independent from the quantity produced (the latter being exogenously set and the firm has access to an end-of-pipe abatement), the technology transfer has no impact on the profits nor on the consumer surplus. Hence, the transfer only decreases the emissions from the South. The North is always willing to transfer its technology and consequently decrease the southern emissions intensity. The same result holds when the transfer decreases the abatement cost parameter

4 Technology transfer with environmental cooperation

In this section, we consider a new scenario in which an international environmental agreement setting pollution caps in the two regions has been reached. We examine the incentives in favour of technology transfer in this institutional regime taking into account that transfer leads to a revision of the original agreement. We proceed in two stages. We first characterize the cooperative environmental regulation before and after transfer. Then we look at the North's incentive to share its technology.

To characterize the cooperative regulation, we assume that the two regions jointly choose the emission caps that maximize overall social welfare and that the regions' commitments are enforceable. These two assumptions are arguably strong. There is actually a significant game-theoretic literature which precisely seeks to inject non-cooperative ingredients into the analysis of international agreements (see Finus (2008) for a recent survey of the literature). The focus of this paper is different. We concentrate analysis on unilateral governmental incentives to share technologies. Put differently, we do not analyze the conditions under which a cooperation is possible but how the conditions to transfer are altered if cooperation emerges.

It is easier to start characterizing the cooperative equilibrium after transfer as the two regions are symmetric at this stage (in particular, μ is the emission intensity in both regions). The regions jointly solve:

$$\max_{E_N, E_S} W = CS_N + \pi_N + CS_S + \pi_S - (\lambda_N + \lambda_S)(E_N + E_S) \tag{9}$$

Plugging (3)-(6) and setting emission intensity in the South to μ, overall welfare can be rewritten as follows:

$$W = (E_N + E_S)\left(\frac{a_S + a_N}{\mu} - \frac{E_N + E_S}{2\,\mu^2} - \lambda_S - \lambda_N\right) + \frac{(a_S - a_N)^2}{2} \tag{10}$$

which is a function of the total emissions $E_N + E_S$. By deriving (10) with respect to $E_N + E_S$, we obtain:

$$\frac{\partial\, W}{\partial\,(E_N + E_S)} = \frac{a_S + a_N}{\mu} - \frac{E_N + E_S}{2\,\mu^2} - \lambda_S - \lambda_N - \frac{E_N + E_S}{2\,\mu^2} = 0 \tag{11}$$

by rearranging, we obtain the level of emissions after transfer that maximizes overall welfare.

Lemma 3. *When the two regions cooperate to set emission caps, their caps after transfer are such that* $\hat{E}_N^1 + \hat{E}_S^1 = \mu\,(a_S + a_N - (\lambda_S + \lambda_N)\,\mu)$.

Note that this expression highlights in a very transparent way the trade-off between the economic benefits – the consumer surplus and the profits centrally driven by the world market size $a_N + a_S$ – and the environmental cost captured by the term $(\lambda_S + \lambda_N)\mu$. The lemma only defines total emissions, not the sharing rule between the two regions. One focal solution is to share this overall level of emission equally between the two regions (as they are symmetric), but other allocation rules are possible. Importantly, burden sharing has here no impact on total welfare. It only has distributional impacts.

Importantly, this reasoning is only valid if a binding regulation and non-negative consumption are assumed. Simple calculations show that this holds true if:

Assumption 3.

$$a_N + a_S \leq 3\,\lambda_S\,\mu + 3\,\lambda_N\,\mu$$

$$2\,a_N \geq \lambda_S\,\mu + \lambda_N\,\mu$$

$$2\,a_S \geq \lambda_S\,\mu + \lambda_N\,\mu$$

The cooperative environmental regulation before transfer is easily derived from Lemma 3. As the North has a superior technology allowing for greater production accompanied by less pollution, production should be entirely located in the North. Hence:

Lemma 4. *When the two regions cooperate to set emission caps, total emissions before transfer are the same as total emissions after transfer* $\hat{E}_N^1 + \hat{E}_S^1$*. But production is entirely located in the North.*

The North has thus no incentive to transfer technology: As emissions and production are the same, environmental damage and the consumer surplus remain unchanged after the transfer. The only difference is that production initially located in the North partly moves to the South, reducing profit in the North and increasing it in the South. Hence:

Proposition 4. *When environmental regulations are set cooperatively, the northern government is never willing to transfer the technology to the South.*

This result is in sharp contrast to the scenario without environmental cooperation in which the North could accept sharing technologies in certain circumstances, in particular if it reduces overall emissions. The major difference is precisely that the presence of environmental cooperation implies no environmental benefit of the transfer here as the level of global emissions remains the same. In this context, the transfer only deteriorates the northern firm's competitiveness.

5 Implications for climate negotiations and conclusions

We now use the above results to discuss the implications for the international climate negotiation process. To simplify, Proposition 3 states that the North primarily views technology transfer as a tool to curb emissions in the South. If it cannot perform that function, the northern government will never accept to share its technologies.

Importantly, inducing emission reductions is necessary but not sufficient to achieve a transfer due to international trade. Without trade, firms would not compete and providing the technology to the southern firm would have no effect on the northern product market, and thus on consumer surplus and profits. It would simply affect emissions. This would have two implications. First, the firm owning the technology would be indifferent to the transfer. Second, the northern government would promote transfer in all cases where it reduces emissions. As this condition is laxer, this means that the presence of international trade hinders technology transfer. As an application, our analysis states here that the international diffusion of technologies in the electricity sector is more likely than in sectors with fierce international competition.

Turning next to proposition 4, we have shown that the North will not share its technologies ex post if a climate agreement has previously been reached. The reason is that the transfer is no longer useful to reduce emissions if cooperation is already in place.

These two propositions thus suggest that, from the North's perspective, technology transfer and environmental cooperation are substitutes. It then ensures immediately, from the northern point of view, that environmental cooperation strictly dominates the transfer as it fully internalizes the global environmental externality and locates world production in the North. The preferences of the South are more complex. Under environmental cooperation, its profit is zero and consumer surplus is lower than with transfer without cooperation, but emissions are lower. Simple calculations yield that $W_S\left(0, \hat{E}_N^1 + \hat{E}_S^1 \mid \ \mu_S = \mu^0\right) > W_S\left(E_S^1, E_N^1 \mid \mu_S = \mu\right)$ is equivalent to $(17\,\lambda_S + \lambda_N)\mu - 16\,a_S > 0$. We can then write:

Proposition 5. *In terms of social welfare, the North consistently prefers environmental cooperation over unilateral technology transfer. The welfare ranking for the South is ambiguous. It will prefer cooperation if its market is small (a low a_S) and if both regions have high environmental willingness to pay.*

The two regions may thus have diverging or converging views about which mode of regulation is preferable. But what happens if the technology transfer is part of a general agreement including both a commitment by the North to share its technology and cooperative emission caps? Lemmas 3 and Lemma 4 give clear indications. Including transfer commitments in the international agreement does not modify the global surplus; it is a purely distributive transfer of profits towards the South. Including technology transfer in the negotiations thus provide the parties with an additional channel to transfer utility. In the real-world, the size of monetary transfer is a central and controversial issue in the negotiations. In the 2015 Paris Agreement, it is stated that, "to help developing countries switch from fossil fuels to greener sources of energy and adapt to the effects of climate change, the developed world will provide $100 billion a year". Our analysis suggests that technology transfer in a climate agreement can provide an additional tool to compensate the South. In this sense, including technology transfer may facilitate the emergence of environmental cooperation, but with no direct effect on total surplus.[11]

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Appendices

A Conditions for environmental policies to be binding

The regulation is binding in both regions if $r_i\,\mu_i \geq E_i$ for $i = \{N, S\}$. This assumption is satisfied if $\tilde{r}_N \mu_N \geq E_N$ and $\tilde{r}_S\,\mu_S \geq E_S$ where $\tilde{r}_i$ denotes the quantity that maximizes π_i given that $r_j = \frac{E_j}{\mu_j}$. $\tilde{r}_i$ is then given by $\tilde{r}_i = \frac{(a_i+a_j)\,\mu_j - E_j}{2\mu_j}$. Thus the regulation is binding if:

$$(a_i + a_j)\ \mu_i\,\mu_j - 2\,E_i\,\mu_j - E_j\,\mu_i > 0,\ \forall\, i \neq j$$

To obtain assumptions 1-3, we simply need to replace the caps E_i and E_j by their value.

B Proof of lemma 1

$$\frac{\partial\, W_N}{\partial\, E_N} = \frac{1}{2\,\mu^2\,\mu^0}\,(a_S\,\mu\,\mu^0 + 3\,a_N\,\mu\,\mu^0 - E_N\,\mu^0 - E_S\,\mu) - \frac{E_N}{\mu^2} - \lambda_N = 0$$

gives the reaction function $E_N(E_S) = \frac{\mu\,(-2\,\lambda_N\,\mu + a_S + 3\,a_N)}{3} - \frac{E_S\,\mu}{3\,\mu^0}$. By symmetry, the reaction function for the South is $E_S(E_N) = \frac{\mu^0\,\left(-2\,\lambda_S\,\mu^0 + a_N + 3\,a_S\right)}{3} - \frac{E_N\,\mu^0}{3\,\mu}$. By replacing $E_S(E_N)$ in $E_N(E_S)$, we obtain the emissions caps given by Lemma 1.

C Proof of proposition 2

The transfer is equivalent to a decrease in μ^0:

$r_S^0 = \frac{1}{4}\,(\lambda_N\,\mu - 3\,\lambda_S\,\mu^0 + 4\,a_S)$, $\frac{\partial\, r_S^0}{\partial\,\mu^0} = -\frac{3\,\lambda_S}{4}$;

$\pi_S^0 = \frac{1}{8}\left(\lambda_N\,\mu - 3\,\lambda_S\,\mu^0 + 4\,a_S\right)\,\left(\lambda_S\,\mu^0 + \lambda_N\,\mu\right)$; $\frac{\partial\,\pi_S^0}{\partial\,\mu^0} = \frac{\lambda_S}{4}\,\left(2\,a_S - 3\,\lambda_S\,\mu^0 - \lambda_N\,\mu\right)$

From assumption 1, $2\,a_S - \frac{5}{2}\,\lambda_S\,\mu^0 - \frac{1}{2}\,\lambda_N\,\mu < 0$. Thus, $\frac{\partial\,\pi_S^0}{\partial\,\mu^0} < 0$

$r_N^0 = \frac{1}{4}\,\left(\lambda_S\,\mu^0 - 3\,\lambda_N\,\mu + 4\,a_N\right)$; $\frac{\partial\,r_N^0}{\partial\,\mu^0} = \frac{\lambda_S}{4}$

$\pi_N^0 = \frac{1}{8}\left(\lambda_S\,\mu^0 - 3\,\lambda_N\,\mu + 4\,a_N\right)\,\left(\lambda_S\,\mu^0 + \lambda_N\,\mu\right)$; $\frac{\partial\,\pi_N^0}{\partial\,\mu^0} = \frac{\lambda_S}{4}\,\left(\lambda_S\,\mu^0 - \lambda_N\,\mu + 2\,a_N\right)$

From $E_N^0 = \frac{\mu}{4}\,\left(\lambda_S\,\mu^0 - 3\,\lambda_N\,\mu + 4\,a_N\right) > 0$, $\frac{\partial\,\pi_N^0}{\partial\,\mu^0} > 0$. $\frac{\partial\,E_N^0}{\partial\,\mu^0} = \frac{\lambda_S\,\mu}{4} > 0$

$p^0 = \frac{1}{2}\,\left(\lambda_S\,\mu^0 + \lambda_N\,\mu\right)$; $\frac{\partial\,p^0}{\partial\,\mu^0} = \frac{\lambda_S}{2}$. Since the consumer surplus decreases with the price, the transfer increases the consumer surplus.

D Proof of proposition 3

(i) The transfer increases emissions if $E_N^0 + E_N^0 < E_N^1 + E_S^1$, that is if:

$$3\,\lambda_S\,\mu^0 + 2\,\lambda_S\,\mu - \lambda_N\,\mu - 4\,a_S > 0 \tag{12}$$

If so, the North only transfers its technology if $\pi_N^0 + CS_N^0 < \pi_N^1 + CS_N^1$. Yet the sign of $\pi_N^0 + CS_N^0 - (\pi_N^1 + CS_N^1)$ is given by:

$$3\,\lambda_S\,\mu^0 + 3\,\lambda_S\,\mu - 2\,\lambda_N\,\mu = \underbrace{3\,\lambda_S\,\mu^0 + 2\,\lambda_S\,\mu - \lambda_N\,\mu - 4\,a_S}_{>0 \text{ from } (12)} + \underbrace{4\,a_S + \lambda_S\,\mu - \lambda_N\,\mu}_{>0 \text{ from assumption } 1} \tag{13}$$

Thus if $E^0 < E^1$, $\pi_N^0 + CS_N^0 > \pi_N^1 + CS_N^1$, and the North never transfers.

(ii) The North transfers if (8) is positive.

$\frac{\partial\,(8)}{\partial\,\lambda_S} = -6\,\left(\left(\lambda_S + \lambda_N\right)\,\left(\mu^0 + \mu\right) + \lambda_N\,\mu^0\right) < 0$; $\frac{\partial\,(8)}{\partial\,a_S} = 16\,\lambda_N$; $\frac{\partial\,(8)}{\partial\,\mu^0} = -3\,\lambda_S\,\left(\lambda_S + 4\,\lambda_N\right)$

The North has more incentive to transfer when λ_N is large:

$\frac{\partial\,(8)}{\partial\,\lambda_N} = 2\,\left(4\,\lambda_N\,\mu + 8\,a_S - 6\,\lambda_S\,\mu^0 - 3\,\lambda_S\,\mu\right)$.

However, (8) $= 2\,\lambda_N\,\left(4\,\lambda_N\,\mu + 8\,a_S - 6\,\lambda_S\,\mu^0 - 3\,\lambda_S\,\mu\right) - \left(3\,{\lambda_S}^2\,\left(\mu^0+\mu\right) + 4\,{\lambda_N}^2\,\mu\right)$.

Thus, the North only considers transferring if $\frac{\partial\,(8)}{\partial\,\lambda_N} > 0$

(iii) Since the North only transfers its technology when $E^0 > E^1$ and since $\frac{\partial\,p^0}{\partial\,\mu^0} > 0$ and $\frac{\partial\,\pi_S^0}{\partial\,\mu^0} < 0$, it is clear that the South always accepts the transfer.

E Proof of lemma 4/proposition 4

$$\max_{E_N, E_S} W = CS_N + \pi_N + CS_S + \pi_S - (\lambda_N + \lambda_S)(E_N + E_S) \tag{14}$$

Plugging (3)-(6), overall welfare can be rewritten as follows:

$$W = \frac{\left(a_S - a_N\right)^2}{2} - \frac{\left(E_N\,\mu^0 + E_S\,\mu\right)^2}{2\,\mu^2\,{\mu^0}^2} + \frac{\left(a_S + a_N\right)\,\left(E_N\,\mu^0 + E_S\,\mu\right)}{\mu\,\mu^0} - \left(E_S + E_N\right)\,\left(\lambda_N + \lambda_S\right)$$

$$\frac{\partial\,W}{\partial\,E_N} = -\frac{E_N\,\mu^0 + E_S\,\mu}{\mu^2\,\mu^0} + \frac{a_S + a_N}{\mu} - \lambda_N - \lambda_S \tag{15}$$

$$\frac{\partial\,W}{\partial\,E_S} = -\frac{E_N\,\mu^0 + E_S\,\mu}{{\mu^0}^2\,\mu} + \frac{a_S + a_N}{\mu^0} - \lambda_N - \lambda_S \tag{16}$$

(15)=0 implies (16)<0. Thus at equilibrium $E_S = 0$ and $E_N = \mu\,\left(a_S + a_N - \left(\lambda_S + \lambda_N\right)\mu\right)$.

By comparing the welfare of the two regions under environmental cooperation with and without transfer, we can easily show that:

$$
\begin{aligned}
& W_N\left(\hat{E}_N^1+\hat{E}_S^1, 0 \mid \ \mu_S=\mu^0\right)-W_N\left(\hat{E}_N^1, \hat{E}_S^1 \mid \mu_S=\mu\right) \\
& =W_S\left(\hat{E}_S^1, \hat{E}_N^1 \mid \mu_S=\mu\right)-W_S\left(0, \hat{E}_S^1+\hat{E}_N^1 \mid \mu_S=\mu^0\right) \\
& =\frac{\left(\lambda_N+\lambda_S\right) \mu}{2}\left(a_S+a_N-\lambda_S \mu-\lambda_N \mu\right)
\end{aligned}
$$

F Proof of proposition 5

The North prefers environmental cooperation over unilateral transfer:

$$
W_N\left(\hat{E}_N^1+\hat{E}_S^1, 0 \mid \ \mu_S=\mu^0\right)-W_N\left(E_N^1, E_S^1 \mid \mu_S=\mu\right)=\frac{\left(\lambda_N+\lambda_S\right) \mu}{16}\left(-15 \lambda_S \mu+\lambda_N \mu+16 a_S\right)
$$

$$
-15 \lambda_S \mu+\lambda_N \mu+16 a_S=\underbrace{8\left(2 a_S-\left(\lambda_N+\lambda_S\right) \mu\right)}_{>0 \text{ from assumption } 3}+\underbrace{\left(9 \lambda_N-7 \lambda_S\right)}_{>0 \text{ from } \lambda_N>\lambda_S} \mu
$$

$$
W_S\left(0, \hat{E}_N^1+\hat{E}_S^1 \mid \ \mu_S=\mu^0\right)-W_S\left(E_S^1, E_N^1 \mid \mu_S=\mu\right)=\frac{\left(\lambda_N+\lambda_S\right) \mu}{16}\left(17 \lambda_S \mu+\lambda_N \mu-16 a_S\right)
$$

In what follows, we compare the equilibrium when there is environmental cooperation and transfer and unilateral transfer:

$\hat{p}^1-p^1=\frac{\mu}{2}\left(\lambda_S+\lambda_N\right)$

Since the consumer surplus decreases with the price, $\hat{SC}_i^1<SC_i^1$.

$\hat{\pi}_N^1-\pi_N^1=\frac{\left(\lambda_S+\lambda_N\right) \mu}{8}\left(4 a_S-5 \lambda_S \mu-\lambda_N \mu\right)$ and $\hat{\pi}_S^1-\pi_S^1=\frac{\left(\lambda_S+\lambda_N\right) \mu}{8}\left(4 a_N-\lambda_S \mu-5 \lambda_N \mu\right)$

From assumption 2, it is clear that $\hat{\pi}_i^1<\pi_i^1$. For each firm, the profit is lower with environmental cooperation and transfer than without environmental cooperation and transfer.

$\hat{\pi}_N^1 < \pi_N^1$ and $\pi_N^0 > \pi_N^1$, does not contradict the fact that $\hat{\pi}_N^1$ can be larger than π_N^0. Indeed, if $\hat{\pi}_N^1 > \pi_N^0$, the North does not transfer and thus π_N^1 is irrelevant.

$$\hat{E}_N^1 - E_N^1 = \frac{\mu}{4}\left(-3\,\lambda_S\,\mu + \lambda_N\,\mu + 2\,a_S - 2\,a_N\right) = -\frac{\mu}{4}\left(\frac{5\,\lambda_S\,\mu + \lambda_N\,\mu - 4\,a_S}{2} + \frac{\lambda_S\,\mu - 3\,\lambda_N\,\mu + 4\,a_N}{2}\right)$$

From assumption 2, the first term is positive and from $E_N^1 > 0$, the second term is positive: $\hat{E}_N^1 < E_N^1$.

$$\hat{E}_S^1 - E_S^1 = \frac{\mu}{4}\left(\lambda_S\,\mu - 3\,\lambda_N\,\mu - 2\,a_S + 2\,a_N\right) = -\frac{\mu}{4}\left(\frac{5\,\lambda_N\,\mu + \lambda_S\,\mu - 4\,a_N}{2} + \frac{\lambda_N\,\mu - 3\,\lambda_S\,\mu + 4\,a_S}{2}\right)$$

From assumption 2, the first term is positive and from $E_S^1 > 0$, the second term is positive: $\hat{E}_N^1 < E_N^1$.

$$\hat{E}^1 - E^1 = -\frac{1}{2}\left(\lambda_S + \lambda_N\right)\,\mu^2$$

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