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Clean technology transfers and North-South technological gap: An important issue for environmental policies

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Abstract. This paper aims at discussing the main stakes of clean technology transfer between the North and the South in a context of economic globalization and climate change. We present a model of environmental taxation between two asymmetric countries, the North and the South. It shows that (i) there exists a technological gap between the North and the South which results from an imperfect absorptive capability of the South; (ii) this absorptive capability defines the rate of innovation in clean technologies for the South; (iii) this technological gap contributes to explain why the South pollutes more than the North in a non-cooperative game in which the environmental tax rates determine the location of the firms; (iv) cooperation is possible only if a financial transfer between the North and the South can be set. This financial transfer is a measure of the cost of this so-called Win-Win strategy.

JEL Classification: F18, H23, Q54, O33.
Keywords: Clean Technology Transfer; Global Warming; Environmental Taxation; The "Pollution Haven" Hypothesis.

Résumé. Nous présentons un modèle de taxation environnementale instaurée entre deux pays asymétriques, le Nord et le Sud. Il montre i) l'existence d'un *gap* technologique entre le Nord et le Sud dû à une capacité d'absorption imparfaite par le Sud ; ii) la capacité d'absorption qui reflète le taux d'innovation dans les technologies propres du Sud ; iii) que ce *gap* technologique explique pourquoi le Sud pollue plus que le Nord dans un contexte non coopératif où les taux d'imposition environnementale conditionnent la localisation des entreprises ; iv) que seul un transfert financier du Nord vers le Sud peut permettre la coopération. Celui-ci mesure le coût de la stratégie « gagnant-gagnant ».

Classification *JEL*: F18, H23, Q54, O33.
Mots-clefs: Transfert de technologie propre ; réchauffement climatique ; Taxation environnementale ; l'hypothèse de « paradis de pollution ».

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1. Introduction

The development and widespread diffusion of clean technologies are one of the answers given by the international community to the increase of global warming. According to Aghion, Hemous and Veugelers (2009), while some emerging countries such as China and Brazil are already part of the global innovation machine, most of the `South', particularly the poorer South, can at best only imitate/adopt green technologies previously invented in the developed countries – where these are available at low cost. Thus if developed countries direct change towards clean technologies and subsequently facilitate the diffusion of new clean technologies to developing countries, a major step towards overcoming global climate change can be taken. Thus, one of the central elements to mitigate climate change leans on the ability of developing countries to adopt clean technologies, due to the access conditions (in terms of price and property rights) of these technologies. The Clean Development Mechanism is precisely one of the instruments, proposed within the framework of the Kyoto Protocol, aiming at diffusing cleaner technologies in developing countries. The principle at the origin of this mechanism seems rather simple. Technologies conceived by the North would be transferred to the South in order to:

– reduce their emissions and converge towards a harmonisation of environmental norms between the North and the South;
– contribute to the development of the South and thus converge towards a homogenisation of economic performances between the North and the South.

But such a Win-Win scheme seems difficult to implement. First, environmental and social effects of technological innovations -even the cleaner ones- are debated, in particular in the context of an ever more globalized world. Nothing guarantees indeed that cleaner technologies will spread and replace traditional products and processes everywhere. Second, even if the main proponents of the Environmental Kuznet's Curve hypothesis argue that at higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in levelling off and gradual decline of environmental degradation (Panayotou, 1993), there is no clear empirical evidence that such an hypothesis is occurring (Kearsley and Riddel, 2009). Third, even though programmes aiming at strengthening clean technology transfers have been developed, the technological gap between the North and the South is still important and this gap is reducing mainly in intermediate countries such as China, India and Brazil. Most of the poorest developing countries are still in a poverty trap and even if there is no connection between poverty and environmental degradation (the poverty-environmental degradation nexus) the capacity of developing countries to receive, manage and develop clean technologies remains low.

Moreover, although mechanisms such as the Kyoto Protocol (and other multilateral environmental agreements) deal with global environmental issues, none of the agreements have universal membership. This imbalance could lead to conflict as treaty-member countries adopt measures to comply with the global agreements, which could be made binding on countries who are not parties to the same treaties. More specifically, in the literature, there are voices arguing that quantity limits are particularly troublesome where targets must adapt to differential economic conditions, uncertain technological change, and evolving science. For regulating global public goods like global warming, the message is that because of its conceptual simplicity, an harmonized pollution tax might prove simpler to design and maintain than a quantity mechanism like the Kyoto Protocol (Nordhaus, 2008; Schubert, 2009).

Thus, what are the existing barriers to clean technology transfers between developed and developing countries? What is the link between the technological gap, the absorption capacity of developing countries and the level of pollution, in the case of clean technology transfers? Can environmental taxation be a better incentive design for promoting green innovation in the southern countries? In Section 2, we highlight the economic, social and ecological impacts of clean technology transfers. In Section 3, we use a model to address the links between North-South fiscal trade-offs, technological catch-up and environmental quality so as to show the feasibility conditions of the Win-Win hypothesis.

2. Economic, social and environmental aspects of clean technology transfer

Clean technologies transfers from a firm holding a patent to the users of products and processes integrating these technologies, suppose to locate our reasoning downstream from the phases of diffusion and use of the product or process. Developing countries constitute a particularly attractive market due to the growing number of potential users. In addition, demographic expansion coupled with industrial development rates of developing countries will inevitably increase the greenhouse gas emissions, and the adoption of stricter environmental standards can help to limit such an increase. Authors even argue that some of the clean technologies would lower the costs of the manufacturing process and could thus facilitate their diffusion and adoption (Blackman, 1997).

Accordingly, the challenge constituted of cleaner technologies in developing countries is economic and ecological. Nevertheless, the idea of transferring (knowledge, know-how and technology) is neither linear nor automatic. Successful transplants of technology depend as much upon willingness and ability to transfer technical knowledge and skills as upon the absorptive capabilities of recipients (Rogers, 2004).

There are at least three modes of technology transfers: the first way to transfer technology is to provide goods incorporating the technology; the second way is to license the capability to produce the product; the third one is to support the development of national capability to research and develop the product independently from a licensor (Barton, 2007). In the field of clean technologies, the issue of capacity building of developing countries remains important.

An OECD working group on technology for a sustainable environment (OECD, 2000) stressed a decade ago the ambiguity of the relation between innovation and technology, economic growth and sustainable development: sustainable development depends on the application of clean technologies on a broad scale by non-OECD as well as OECD countries. A special challenge is to enable developing countries to take full advantage of energy efficient and cleaner production options to adapt them to their needs. The main constraints in many of these countries relate to a lack of human, institutional, technical, managerial and financial capacities to manage technological change. Support for the dissemination of technological know-how, therefore, must concentrate first on capacity development to underpin the long-term application of new technologies. Since the private sector is the largest source of finance to cleaner production and a major actor in technology innovation, diffusion and application, policy efforts should also focus on providing the private sector with an open, competitive and sound policy environment.[2]

Moreover, the hypothetical relation between technology transfer and convergence of the growth rates invites us to question the pollution haven hypothesis (Copeland and Taylor, 1994) in the case of clean technology transfer. Let us remind you that according to this hypothesis, lax environmental standards and enforcement in developing countries intensify pollution further by attracting investment in pollution-intensive industries from developed countries. Economic globalization and trade liberalization are likely to change the relation between economic growth, competitiveness and the environment and to generate economic behaviours allowing the existence of pollution havens.

Indeed, market competition would provoke a global competition between producers and would lead them to produce at the lowest price and to search for the country where labour is the cheapest, the production costs are kept low and where regulation is unrestricted. We have noticed elsewhere the process of relocation of the car industry. Therefore, a country with cheap labour and without strict environmental regulation will not be incited to change for stricter environmental norms because of the risk of relocation of industries towards more tolerant countries. Such a prisoner's dilemma would explain in a certain extent why environmental norms have so many difficulties to diffuse in countries where the reduction potential is highest. Several authors have seen in such an opportunity a disguised means to justify development aid. For instance, in February 1992, an internal memo of the chief economist of the World Bank, Lawrence Summers, provoked debates and controversies about the ethical and economic conditions of the relocation of polluting industries in poor countries. Lawrence Summers, who denied this interpretation and advocated a different position during the controversy, argued in his memo for the opportunity to relocate polluting industries from North to South (Swaney, 1994). Among his arguments, the existence of low production and labour costs was advanced. But more controversial was the following idea, reflecting a value judgement on the price of life: the sanitary costs generated by the pollution emissions are supposed to be far less important for society if these emissions are affecting inhabitants of a country where the income *per capita* is the lowest.

2. OECD (2000), p. 22.

Box 1

The impact of clean technology transfer on the reduction of greenhouse gas emissions: An important issue

There is a wide range of bilateral and multilateral programs in charge of the promotion of technology transfer between countries. Most of these programs are developed within the framework of international mechanisms aiming at limiting greenhouse gas emissions at the global level. Indeed, the adoption of new environmentally friendly techniques and processes is a crucial stake in the reduction of greenhouse gas emissions.

The United Nations Framework Convention on Climate Change (UNFCCC) stresses (in paragraph 4.7) the importance of international partnerships aiming at adopting clean technologies in developed as well as in developing countries: "*The extent to which developing country Parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed Parties of their commitments under the Convention related to financial resources and transfer of technology and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties*" [United Nations (1992), article 4.7, p. 14]. But more pragmatically, the member States of the Convention have adopted instruments of bilateral and multilateral co-operation between developed countries (Joint Implementation) and between developed and developing countries (Clean Development Mechanism). These instruments are strengthening the actions already engaged with the support of the Global Environment Facility (GEF).

The Clean Development Mechanism was introduced in 1997 during the Kyoto Protocol, in order to bear the costs of the reduction of greenhouse gas emissions. Article 12 of the Kyoto Protocol defines the implementation modalities of this mechanism, created as an outcome of the mechanism of Joint Implementation. This article states that developing countries must benefit from this mechanism and receive "Certified Emission Reductions". Besides, these reductions also benefit to the Annex 1 countries, because they partly contribute to fulfil their commitments.

However, the pollution haven hypothesis reveals difficulties to be empirically proven. For instance, Letchumanan and Kodoma (2001) do not find any positive correlation in their statistical tests, between the pollution content of several basic industries and the amount of FDI concerning those industries. On the contrary, statistical tests in Thailand and Singapore would show that the most important investments would be located in relatively clean industries. These authors also argue that the location of industries at the global level would be driven by technology transfer concerning products as well as processes. Technological innovations of processes would, for instance, favour an international division of labour and would partly explain the location of industries and their repartition between North and South. The latter argument however needs to question all the aspects linked to the location of industries and of clean technology transfer, in relation with institutional and organisational factors.

3. The model

We take a partial equilibrium model with two asymmetric countries and differential environmental taxation.[3] We assume that these two countries are contiguously located on the interval [−1; 1]. The border is at point 0, with the Foreign country, the *North*, located to the left and the Home country, the *South*, located to the right. Firms are characterised by their location ϕ in this interval. Within each country, firms are uniformly distributed.

3.1. North-South asymmetries

The number of firms, however, may differ between the two: there are N_s southern firms and N_n northern firms. The relative size of the two economies is measured by the relative number of firms:

$$\theta = \frac{N_s}{N_n} \tag{1}$$

No one would contest that firms play a significant role for the economic development, and their number can be considered as a measure of the development level of an economy. However, the strategy of the firms is also a critical dimension for development. With reference to the notion of entrepreneurship, among the activities of a firm, innovation is fundamental while being subject to adverse selection and moral hazard. This is mainly because the innovator is likely to have much better information about the chances of success than potential investors. The latter are unlikely to have the knowledge required to effectively monitor the innovation project. Another key feature of investment in innovation is that much of it goes into *intangible assets*, such as the specialised knowledge embodied in researchers.

In this context, we assume that the level of technological knowledge used by the southern firms results in the one produced by the northern firms, $T_s - \tau$. This technological knowledge is used to reduce pollution per unit of output. In other words, it is used to generate clean technologies. The rate at which the northern technology, $\overline{T}$, is realised in improved technological practice, τ, in the southern country depends upon the absorptive capabilities of the southern firms, $d(a)$; a designates here the endowment in immobile assets.[4] This rate of technological progress also depends on the gap between the level of technology observed in the northern country and the level of technology in the southern country. Specifically $\frac{d\tau}{dt}\frac{1}{\tau} = d(a)\frac{[T-\tau]}{\tau}$, or equivalently $\frac{\dot{\tau}}{\tau} \equiv g_\tau \equiv \frac{d\tau}{dt}\frac{1}{\tau} = d(a)\frac{[T-\tau]}{\tau}$, with $d(0) = 0$ and $d'(a) > 0$.

3. The model is mainly based on Kanbur and Keen (1993). It has also been inspired by Kunce and Shogren (2002), as well as Cander and Tulkens (1997). It differs from this literature with respect to environmental taxation and technological asymmetry between the two countries.

4. For Nelson and Phelps (1966), it is mainly the level of human capital that defines the absorptive capabilities of an economy. We observe the same kind of approach with some theoreticians of the so-called endogenous growth theory (Aghion and Howitt, 1998). De Long and Summers (1993) use the share of equipments in global output as a proxy of the absorptive capabilities of the recipient economy. Finally, Acemoglu and Zilibotti (2001) propose the complementarity between (southern) low-skill labour and (northern) high-skill labour as a perquisite for technological catch-up.

The opportunity for the South to reduce its technological gap with the North mainly depends upon the conditions of adopting and using clean technologies. Thus the southern firms are in a weak position in respect to the «clean» technological frontier (Bjorvatn and Eckel, 2006). With reference to Nelson and Phelps (1966), we do consider that any higher absorptive capabilities accelerate the technological catch-up. If $\overline{T} = e^{g_{\overline{T}} t}$ and $\frac{da}{dt} = 0$, it is then easy to show that the North-South technological gap converges towards a constant positive value :

$$b = \frac{1}{d(a)} \frac{\dot{\overline{T}}}{\overline{T}} = \frac{g_{\overline{T}}}{d(a)} \tag{2}$$

If $a > 0$, the rate of increase of the level of technology in practice in the South settles down to $g_{\overline{T}}$, independently of the endowment in immobile assets. The gap decreases until, in the limit, g_{τ} has fallen to the value $g_{\overline{T}}$ at which point the technological gap remains constant. This asymptotic technological gap between the North and the South is a decreasing function of the endowment in immobile assets. Thus increased endowment in immobile assets increases the path of the technology currently used by the southern firms.

With reference to the Win-Win hypothesis, the constant value of the technological gap between the Northern firms and the Southern firms expresses the idea that an economy can gain from its technological gap when it disposes of a certain absorptive capability, which depends upon its endowment in immobile assets required for absorption. Total factor productivity growth may thus differ across countries, at least for a transitional period, depending on both the absorptive capability of a nation and the observed technological gap. In other words, according to Abramovitz (1989), only those poorer countries that benefit from a high absorption social capability will be able to catch up. For the others, this gap would be persistent over the long run.

3.2. Environmental policy and attractiveness

In each country, firms have two options: they can either decide to produce in their own country i, or they can produce in the foreign country $j \neq i$, $(j, i = n, s)$, just over the border, and export back to the original location. The net profit can be defined as follows :

$$\upsilon_{i,i}(\pi_{i,i}, p_{i,i}) = \begin{cases} \pi_n - p_n \\ \pi_s - p_s - bp_s = \pi_s - \alpha(b)p_s \text{ , with } \alpha(b) = (1+b) \end{cases} \tag{3}$$

The firm produces if its net profit $\upsilon_{i,i}$ is positive. Profits $\pi_{i,i}$ are identical within each country but may differ between them because of the technological gap. Each firm generates pollution as a by-product. If production takes place in the North (respectively South), a pollution tax $p_{i,i}$ of an amount is paid. In addition, the North and the South do not have access to the same technology, so that emissions are subject to the technological gap between the two countries b. As a result, the southern firm pollutes more than the northern one because of this gap. Environmental regulation takes the form of a taxation on the amount of pollution that a firm may emit in the country where production takes place.[5] In the South, this tax rate is set at $\overline{p_s}$. Since net profits decrease in $\overline{p_s}$ (respectively $\overline{p_n}$), net profit maximisation implies: $p_n = \overline{p_n}$ and $p_s = \overline{p_s}$. Note that an increase in $\overline{p_s}$ means an improvement in environmental quality, (i.e. less pollution). We assume that pollution does not cross international borders.

Relocating and exporting back is assumed to be more costly the further the firm needs to move; accordingly if unit costs are λ, then for a firm located at distance ϕ from the border, total costs are $\lambda\phi$. For brevity, these costs summarise the relocation charges. The parameter is also a measure of integration, with lower corresponding to more openness.

Home firms will decide to relocate abroad if either lower taxation or less stringent environmental regulation is sufficiently attractive to offset the incurred relocation costs. It is straightforward to show that, because of the linearity of relocation costs, all firms between 0 and $\left|\overline{\phi}\right|$ will move to the other country, when:

$$\pi_s - p_n - \lambda\phi > \pi_s - \alpha(b)\, p_s$$

or equivalently:

$$\phi < \frac{\alpha(b)\, p_s - p_n}{\lambda} \tag{4}$$

and when $\pi_s - p_n - \lambda\phi \geq 0$.

At $\overline{\phi} = \frac{\alpha(b) p_s - p_n}{\lambda}$ the attraction of more lenient environmental regulation or lower taxes elsewhere just offset relocation costs; at distances to zero less than $\left|\overline{\phi}\right|$, these advantages strictly dominate relocation costs, and firms will move abroad.

In each country, the objective of the government is taken to be the maximisation of its tax revenue which results from pollution taxation. When the border between the two countries is closed, the two governments can ignore each other in defining their tax rates. At the optimum, the tax rate is defined with respect to local pollution abatement costs:

$\overline{p}_n^c = \pi_n - \upsilon_n$; $\overline{p}_s^c = (\pi_s - \upsilon_s)/\alpha(b)$ where c indicates the closed border.

When the border is openned, the situation changes dramatically. The southern country's objective function equals the welfare derived from the tax revenue of the government. From the linear revenue functions and the discussion of location choice above, this is given by:

$$w_s(\overline{p_s}\ ;\ \overline{p_n}) = \begin{cases} if\ \overline{\phi} \geq 0 \\ w_s = N_s(1-\overline{\phi})\alpha(b)\overline{p_s} \\ w_s = N_s\left(1-\left[\frac{\alpha(b)\overline{p_s}-\overline{p_n}}{\lambda}\right]\right)\alpha(b)\overline{p_s} \\ if\ \overline{\phi} \leq 0\ ; \\ w_s = (N_s + N_n\overline{\phi})\,\alpha(b)\overline{p_s} \\ w_s = \left(N_s + N_n\left[\frac{\alpha(b)\overline{p_s}-\overline{p_n}}{\lambda}\right]\right)\alpha(b)\overline{p_s} \end{cases} \tag{5}$$

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5. With respect to global warming, pollution cannot be treated as a pure transboundary problem, such as acid rain or water carrying pollution. This is the reason why the problem here is not pollution crossing borders but rather mobile firms crossing international borders to find country with the most interesting environmental regulation. However, the environmental quality will be treated as a public good whose production requires cooperation between the two countries.

maximising $w_s(\overline{p_s}\ ;\ \overline{p_n})$, taking as given the pollution tax rate of the northern country, the best response function of the southern country is defined as $\overline{p_s}(\overline{p_n}) = arg\ max_{\overline{p_s}}\{w_s(\overline{p_s}\ ;\ \overline{p_n})\}$.

3.2.1. The case of symmetry

Assuming that the two countries have exactly the same size, $\theta = 1$, the best response function yields:

$$\overline{p_s}(\overline{p_n}) = \begin{cases} \frac{1}{2\alpha(b)}[\lambda + \overline{p_n}]\ ;\ \overline{p_n} \le \lambda \\ \overline{p_n}\ ;\ \overline{p_n} \ge \lambda \end{cases} \tag{6}$$

Because the two countries are symmetric in size, a symmetric function holds for the northern country, namely:

$$\overline{p_n}(\overline{p_s}) = \begin{cases} \frac{1}{2\alpha(b)}[\lambda + \overline{p_s}]\ ;\ \overline{p_s} \le \lambda \\ \overline{p_s}\ ;\ \overline{p_s} \ge \lambda \end{cases} \tag{7}$$

PROPOSITION 1: *Assuming the technological gap between the two countries that are symmetric in size, $\theta = 1$, $\overline{p_{n,s}} \le \lambda$, there exists a unique Nash equilibrium. The equilibrium taxes are:*

$$\hat{p}_s(b) = \hat{p}_n(b) = \left[\frac{1}{(2\alpha(b)-1)}\right]\lambda \tag{8}$$

PROOF: When the two countries are symmetric, the response functions are symmetric. It is then straightforward to show from $\overline{p_n}(\overline{p_s})$ and $\overline{p_s}(\overline{p_n})$ that an equilibrium with $p_s = p_n$ exists if $\theta = 1$ and that the corresponding tax rate is $\left[\frac{1}{(2\alpha(b)-1)}\right]\lambda$.

Because tax rates are identical at the Nash equilibrium with symmetric countries in size, no mobility takes place and the payoffs are:

$$\hat{w}(b) = N\left[\frac{1}{(2\alpha(b)-1)}\right]\lambda \tag{9}$$

It is interesting to note that the pair $(\hat{p}_s(b), \hat{p}_n(b))$ in the presence of a technological gap between the northern country and the southern country is below the one we would observe in the situation of total symmetry. In effect, if $b = 0$, $\alpha(b) = 1$ the equilibrium taxes become: $\hat{p}_s(0) = \hat{p}_n(0) = \lambda$.

As a result, the tax revenues for both countries will be: $w(0) = N\lambda$. The technological gap appears as a "public bad" contributing to decrease both the revenue-maximising tax rates and the corresponding level of environmental quality. The amount of the loss in terms of tax revenue is:

$$\left[\frac{2(\alpha(b)-1)}{(2\alpha(b)-1)}\right]$$

3.2.2. The case of asymmetry

We now turn to the case of asymmetric countries, which differ in their size. Assuming that the South is smaller (in terms of the number of firms) than the North $\theta < 1$, the best response function for the southern country yields :

$$\overline{p_s}\left(\overline{p_n}\right)=\begin{cases}\frac{1}{2\alpha(b)}(\lambda+p_n)\ ;\ p_n\leq\lambda\sqrt{\theta}\\ \frac{1}{2\alpha(b)}(\lambda\theta+p_n)\ ;\ p_n\geq\lambda\sqrt{\theta}\end{cases}\tag{10}$$

Suppose now that each country sets out to maximise its own revenue by choice of environmental regulation, in a non-cooperative Nash setting. Given the North's regulation level $\overline{p_n}$, the South therefore chooses $\overline{p_s}$ to maximise its welfare. The analysis of the problem depends upon the fact that the objective function has a different structure in the two regimes shown: that in which firms go abroad to take advantage of lax environmental regulation or lower taxation. Which of these environmental policy regimes is optimal for a country to be in depends not only on the other country's regulation level and the technological gap, but also on the relative sizes of the two economies.This best response function proposes two different strategic behaviours that are derived from the environmental quality defined by the North.

When $\overline{p_n}<\lambda\sqrt{\theta}$, the optimal policy for the South consists in offering lower environmental tax than the North. In doing so it looses from an increase in domestic pollution, but the revenue gains from the relatively large number of firms which move in from the North more than make up for this. For this range of northern environmental tax, the optimal policy is to attract inward foreign direct investment by offering relatively lax environmental standards, or, in other words, to actually import pollution. This result refers to the pollution haven hypothesis.

When $\overline{p_n}>\lambda\sqrt{\theta}$, it is optimal for the South to tighter environmental regulation. Some firms are lost to the North, but regulation there is so lax that it is not worth matching them given the domestic welfare costs of pollution. The optimal policy is then to export pollution.

According to our supposition about the relative size of the North and the South, the North's best response function can be written as follows:

$$\overline{p_n}\left(\overline{p_s}\right)=\begin{cases}\frac{1}{2\alpha(b)}(\lambda+p_s)\ ;\ \overline{p_s}\leq\lambda\\ \overline{p_s}\ ;\ \lambda\leq\overline{p_s}\leq\frac{\lambda}{\theta}\\ \frac{1}{2\alpha(b)}\left(\frac{\lambda}{\theta}+p_s\right)\ ;\ \overline{p_s}\geq\frac{\lambda}{\theta}\end{cases}\tag{11}$$

Three different fiscal regimes can be defined:

- when $\overline{p_s}<\lambda$, the North imports pollution from the South;
- when $\lambda\leq\overline{p_s}\leq\frac{\lambda}{\theta}$, the environmental standards in the North and in the South are the same. In this case, there is no mobility between the North and the South implying pollution;
- when $\overline{p_s}\geq\frac{\lambda}{\theta}$, it is the North that exports pollution to the South. This result refers to the 'pollution haven' hypothesis.

There is a fundamental asymmetry between the response function of the northern country and the southern country (see APPENDIX 1 for the proof). The environmental regulation will be weaker in the South. When the South undercuts the North by setting a lower pollution tax, it increases pollution domestically through its own firms (which are relatively few in numbers) but experiences a net gain (revenue minus pollution costs) from foreign firms which are relatively numerous and that are now attracted to produce in the South. The South thus has higher incentives to set lax environmental taxation. Even though the northern firms use a cleaner technology than the southern ones, their number entering the South generates a *volume effect* in terms of emissions that cannot be offset by the *quality effect* of their technology.

With respect to the possible strategies for the North and the South, we note that the technological gap leads to a decrease in the world environmental quality. For the South, this gap reveals the absorptive cost of the northern clean technology. Then, it seems rather clear that such a gap induces the environmental policy that would prevail in the South. In addition, it is interesting to show that this gap can also have an indirect impact on the northern environmental quality, according to the terms of trade between the North and the South. Since these two economies aim at maximising their own welfare by choosing the environmental policy which seems optimal according to technological and institutional constraints, the environmental quality of one economy will inevitably influence the environmental quality of the other.

PROPOSITION 2: *Assuming a technological gap and an asymmetry in size between the two countries, there exists a unique Nash equilibrium. The respective pollution tax in the South and in the North is given by:*

$$\hat{p}_s = \left[\frac{2\alpha(b)\theta + 1}{4\alpha(b)^2 - 1}\right]\lambda;\ \hat{p}_n = \left[\frac{2\alpha(b) + \theta}{4\alpha(b)^2 - 1}\right]\lambda \qquad (12)$$

PROOF: The discontinuity in the response function of the small country makes the existence of a Nash equilibrium impossible with $p_s > p_n$. If we consider then the possibility that $p_s < p_n$ in equilibrium, from:

$$p_s(\overline{p_n}) = \begin{cases} \frac{1}{2\alpha(b)}(\lambda + p_n)\ ;\ p_n \leq \lambda \surd \theta \\ \frac{1}{2\alpha(b)}(\lambda\theta + p_n)\ ;\ p_n \geq \lambda \surd \theta \end{cases}$$

we define that $p_s(\overline{p_n}) < p_s$ for some $p_s \in p_s(\overline{p_n})$ if $p_n \geq \lambda \surd \theta$.

In this situation:

$$p_s = \frac{1}{2\alpha(b)}(\lambda\theta + p_n)$$

We consider now the following best response function of the large country:

$$\overline{p_n}(\overline{p_s}) = \begin{cases} \frac{1}{2\alpha(b)}(\lambda + p_s)\ ;\ \overline{p_s} \leq \lambda \\ \overline{p_s}\ ;\ \lambda \leq \overline{p_s} \leq \frac{\lambda}{\theta} \\ \frac{1}{2\alpha(b)}\left(\frac{\lambda}{\theta} + p_s\right)\ ;\ \overline{p_s} \geq \frac{\lambda}{\theta} \end{cases}$$

We define that $\overline{p_n}(\overline{p_s}) > p_s$ for some $p_n \in p_n(\overline{p_s})$ if $p_s < \lambda$.

This situation gives:

$$p_n = \frac{1}{2\alpha(b)}(\lambda + p_s)$$

Solving p_s and p_n gives the respective tax rates $\hat{p}_s$ and $\hat{p}_n$. The condition $\hat{p}_n \geq \lambda / \theta$ for $p_s = \frac{1}{2\alpha(b)}(\lambda\theta + p_n)$ is satisfied if $(2\alpha(b)+\theta)-(4\alpha(b)^2-1)/\theta \geq 0$.

Moreover, the condition $\hat{p}_s < \lambda$ is satisfied as long as $\theta < 1$.

With reference to the symmetric situation between the two countries, it is straightforward to show from $\overline{p_n}(\overline{p_s})$ and $\overline{p_s}(\overline{p_n})$ that an equilibrium with $p_s = p_n$ exists if $\theta = 1$ and that the corresponding tax rate is then $\left[\frac{1}{(2\alpha(b)-1)}\right]\lambda$.

Because tax rates are not identical at the Nash equilibrium for the two countries with uneven size, firms mobility takes place and the payoffs are different:

$$\hat{w}_s = N_n\left[\frac{(2\alpha(b)\theta+1)^2}{(2\alpha(b)+1)(4\alpha(b)^2-1}\right]\lambda \; ; \; \hat{w}_n = N_n\left[\frac{(2\alpha(b)+\theta)^2}{(2\alpha(b)+1)(4\alpha(b)^2-1}\right]\lambda \quad (13)$$

At the Nash equilibrium, each country sets its own marginal abatement cost and marginal damage costs equal. Thus less global abatement and more international pollution occur in the Nash equilibrium. This non-cooperative action defines the country's *threat point*. One central feature of this non-cooperative equilibrium is then immediate: the southern environmental tax rate is now inferior to the northern one. In effect, in equilibrium, the southern country strictly *undercuts* the northern country as is shown by:

$$\hat{p}_n - \hat{p}_s > 0 \Leftrightarrow \frac{\lambda}{4\alpha(b)^2-1}[(2\alpha(b)+\theta)-(2\alpha(b)\theta+1)] > 0 \qquad (14)$$

since $\alpha(b) > 1$, $2\alpha(b)(1-\theta) > (1-\theta)$.

This situation results from the two variables that allow a distinction between the North and the South in our analytical framework: the relative size of these economies, as well as the technological gap between them. However, it is interesting to note that the highest equilibrium tax rate is strictly below the one obtained when the two countries are symmetric in size, $\hat{p}_n < \hat{p}$. In effect, for this non-cooperative equilibrium, both asymmetries play together. The combination of the difference in size and the technological gap leads the South to define a relatively lax environmental regulation compared with the one adopted in the North. Consequently, the additional gain from the relocation of firms largely offset the additional ecological cost resulting from the reduction of the environmental quality. In this context, at the equilibrium, the South tends to specialise in pollution imports, while the North tends to specialise in pollution exports.

The economic situation of the South is worse off compared with the one of the North, since the developing country specialises in second-best technologies. In this respect, we could admit the assumption that the negative consequences of clean technology transfer through the Clean Development Mechanism might dissimulate a few strategies of pollution exports from the North (Tirole, 2009). Then, the target of mitigating greenhouse gas emissions would be only partially reached, but would engender market losses for certain local industries that do not possess the appropriate means to compete against standards and practices of exporters.

3.3. Fiscal cooperation and environmental quality

We consider now a form of fiscal cooperation between these two asymmetric countries. The challenge is that although the two countries have a common interest to protect themselves, they may or may not have a private incentive to abate pollution voluntarily at a socially optimal level. The full cooperation solution that can be defined as the best possible outcome in terms of global welfare is the minimum of the sum of the worldwide pollution abatement costs and pollution damage costs. Since the benefits -the resulting level of environmental quality- generated by pollution abatement are a public good that covers both countries, this solution is given where the sum of marginal damage costs across the two countries are equal to the marginal abatement costs of each country.

In the model, cooperation means that they choose a common tax rate, ρ, so as to maximise both their respective individual fiscal revenues and the global level of environmental quality. In this case, the benchmark is the non-cooperative equilibrium discussed above.

Consider first the southern country. If cooperation were at the higher of the Nash equilibrium taxes, $\rho = \hat{p}_n$ its revenue would be:

$$w_s^{\rho} = w_s\left(\hat{p}_n, \hat{p}_n\right) < w_s\left(\hat{p}_s\left(\hat{p}_n\right), \hat{p}_n\right) = w_s\left(\hat{p}_s, \hat{p}_n\right) = \hat{w}_s \qquad (15)$$

Compared with the non-cooperative equilibrium, fiscal revenue in the southern country would fall. Since revenue in each country is strictly increasing in ρ, cooperation to any $\rho > \hat{p}_s$ deteriorates the situation of the southern country. On the other hand, any harmonisation to the lower of the Nash equilibrium tax rates would reduce revenue in the northern country:

$$w_n^{\rho} = w_n\left(\hat{p}_s, \hat{p}_s\right) < w_n\left(\hat{p}_n\left(\hat{p}_n\right), \hat{p}_s\right) = w_n\left(\hat{p}_s, \hat{p}_n\right) = \hat{w}_n \qquad (16)$$

PROPOSITION 3: *There exists $\tilde{p} \in \left(\hat{p}_s, \hat{p}_n\right)$ such that the southern country benefits from cooperation to ρ if $\rho < \tilde{p}$ and the northern country benefits from cooperation to ρ if $\rho > \tilde{p}$.*

In this situation, both countries do not have interest in cooperation with respect to both the pollution tax rate and the corresponding level of environmental quality. Thus the international optimum cannot be reached without considering the possibility of organising a *financial transfer* or *side-payment* between the two asymmetric countries[6] (Chander and Tulkens, 1997; Verdonck, 2004). Various equilibria might exist which make each country at least as well off, and possibly better off, than under the Nash equilibrium. Such solutions can result from binding offers of side-payments. Such side-payments, combined with optimal tax rates, would guarantee to each country (i) that it gets as much tax revenue as it would get at

6. Many possible schemes of side-payments exist, redistributing the rewards of full or partial cooperation gainers to losers. In the literature, different side-payments are proposed. Compensation can be based on (1) a country's population or (2) the extent each country cooperates (Barrett, 1994). Compensation could also be defined with reference to a Pareto dominant outcome, whereby the sum of abatement and damage costs is minimised subject to the condition that no country is made worse off than under cooperation (Tulkens, 1998).

the Nash equilibrium, and (ii) that in addition a positive share is obtained from the collective surplus made available by cooperation :

$$\left[\left(w_n^{\rho}+w_s^{\rho}\right)-\left(\hat{w}_n+\hat{w}_s\right)\right]>0 \qquad (17)$$

If the two countries were to cooperate, they would maximise joint revenue subject to the highest level of environmental quality that can be reached : $\rho=\hat{\rho}(0)=\lambda$. Each government will extract all the net profit of its own firms by setting its tax at this level: $w_s^{\rho}=\lambda N_s$ and $w_n^{\rho}=\lambda N_n$.

The northern country is always better off with this fiscal cooperation than with fiscal competition. In effect, because $\upsilon_n>\lambda$ and $\theta\in[0,1]$, we have: $w_n^{\rho}-\hat{w}_n>0$. On the contrary, the southern country will get higher tax revenue at the Nash equilibrium than with fiscal cooperation: $\hat{w}_s-w_s^{\rho}>0$. The following form of side-payments is then proposed for the south :

$$h=\left(\hat{w}_s-w_s^{\rho}\right)+\sigma\left[\left(w_n^{\rho}+w_s^{\rho}\right)-\left(\hat{w}_n+\hat{w}_s\right)\right]$$

and equivalently for the North : $H=\left(\hat{w}_n-w_n^{\rho}\right)+(1-\sigma)\left[\left(w_n^{\rho}+w_s^{\rho}\right)-\left(\hat{w}_n+\hat{w}_s\right)\right]$

where $\sigma\in[0,1]$.

Note that $h+H=0$

Thus, we define a *cooperative equilibrium with side-payments* (χ), where tax rates are both set at λ and the southern and the northern countries each get w_s^{ρ} and w_n^{ρ}, plus respectively the side-payments h and H.

$$w_s^{\chi}=w_s^{\rho}+h \text{ and } w_n^{\chi}=w_n^{\rho}+H$$

Since $b>0$ and θ is such that it is not rational for the South to cooperate, cooperation is possible only when the North transfers money to the southern country. As a result, the North gets less than at the cooperative equilibrium, but still gets more than at the Nash equilibrium. The southern country gets as much as at the Nash equilibrium plus the transfer. Compared with the quantity system, the fiscal policy proposes an important advantage for governments: using revenue-raising measures in restricting emissions. Emissions limits give rise to valuable rights to emit, and the question is whether the government or private parties get the revenues. If the pollution constraints are imposed through taxes, and the revenues are recycled by reducing taxes on other goods or inputs, then the increased efficiency loss from taxation can be decreased so that there is no necessary increase in deadweight loss (Nordhaus, 2008). However, the coordination of these fiscal policies yields a cost, the side-payments or transfer, that must be financed. Disregarding the issue of whether compensation can be made in principle for environmental losses, key problems are how to enforce such side-payments in such a way that a country can be sure that, if it undertakes cooperation, compensation will be actually paid. Since there is no supranational authority to internalise global environmental spillovers, only voluntary international agreements can produce the corresponding level of environmental quality.

Since these two economies choose exactly the same tax rate, they reach the same level of environmental quality per unit of output $p^{\chi}(b) = p_s^{\rho}(b) = p_n^{\rho}(b)$.

However, the presence of the technological gap between the North and the South, which influences the world environmental regulation, makes this harmonisation more costly than in the case without the gap. As a result, any form of environmental regulation involving abatement efforts of both the North and the South, imposes a real economic cooperation between these two economies aiming at reducing their asymmetries. The required side-payments should be used to finance investment in the southern assets that would reduce the technological gap. This last proposal shows that the two dimensions of the Win-Win hypothesis are fundamentally interlinked: the feasibility of a certain level of environmental quality is associated with a certain level of economic development. In this perspective, any environmental regulation at the world level must be composed of measures aiming at diminishing the access costs to economic globalization.

Precisely, in the framework of the Kyoto Protocol, one of the central points debated concerning clean technology transfer is the problem of capability building of developing countries (Dechezleprêtre, Glachant and Ménière, 2007). Without a strong involvement of institutions at the local level, the risk is to assist to a double movement in developing countries: on the one hand, a limitation of greenhouse gas emissions, but on the other hand, a reduction in the exports of local and traditional products and processes, considered to be obsolete in foreign countries as well as in the home country. As Quenault (2000) states, "*Finally, the risk is, if there was to be a money or technology transfer within the CDM framework, it would be no longer to help developing countries, but rather to help the Annex I Parties to satisfy their commitments at low cost, by allowing them to buy certified emission reductions. Indeed, the Kyoto Protocol expresses clearly (Article 12.2) that if the aim of the CDM is certainly to assist developing countries to put them on the path of a Sustainable Development, it is also (and maybe stronger in mind of a few ones) to help developed countries to fulfil their calculated commitments in terms of a decrease in their own emissions.*"

We have already stressed how far the success in clean technology transfer was linked to a partnership between countries. Beyond such a reciprocal agreement, we would like to return to a set of barriers that are likely to face the success of clean technology transfer, and to list the factors of success of these transfers. Worrell *et al*. (2001) propose that one of the most important barriers to technology transfer lie in the capacity to manage information, from the innovative firm up to the final user. A large number of firms in developing countries do not dispose of efficient means to convey information -inside as well as outside of the firm-about the advantages of energy efficient technologies. Moreover, there is also a problem of confidence in the delivered information and it generates significant transaction costs. Generally, decision-making mechanism concerning the choice of technology options in a firm is difficult to manage.

Among other factors to take into account for successful technology transfer in developing countries, institutional design is a key element. In a country where technology is transferred, institutional design must encourage diffusion and absorptive capability. Tsipouri (1999) states in particular that a firm must itself be able to innovate and to create knowledge, to gain from the absorption of external knowledge, technology or know-how. Geographic proximity between innovative firms could increase productivity gains linked to the transferred technologies and could generate positive externalities. One of the success conditions for technology transfer is on the ability to create a local network of innovation. Thus, independently of the propensity to offer knowledge, externalities appear to work best in areas where a wider number of agents can both produce and profit from each others knowledge. In addition, limited capital availability coupled with high inflation rates in developing countries contribute to reducing foreign investors' incentives to invest, because of the risks implied in such a context.

4. Conclusion

In this paper, we argued that the issue of clean technology transfer reveals an important stake concerning economic globalization and its influences on world environmental regulation. The reference to the Clean Development Mechanism allows us to address the question of economic development linked with the one of ecological sustainability, and to argue against the performance of the quantity system, such as the Kyoto Protocol, for regulating stock global public goods like global warming. The analytical framework adopted here does not aim at stressing the potential negative impacts of economic globalization. The latter is rather used to underline the relative heterogeneity of economies concerning the costly access conditions to economic globalization.

We proposed a model of environmental taxation between two asymmetric countries in which a critical role is attributed to the absorptive capability, defined as the southern country's endowment in immobile assets. The latter shows that (i) there exists a technological gap between the North and the South which results from an imperfect absorptive capability of the South; (ii) this absorptive capability defines the rate of innovation in clean technologies for the South; (iii) this technological gap contributes to explain why the South pollutes more than the North in a non-cooperative game in which the environmental tax rates determine the location of the firms; (iv) cooperation is possible only if a side-payments scheme between the North and the South can be set. This financial transfer is a measure of the so-called Win-Win hypothesis. The latter should be used to finance investment in the immobile assets that define the level of absorptive capacity. This absorptive capacity contributes to the convergence process of environmental and economic performances between the North and the South. This model leads us to discuss the pertinence of the Win-Win hypothesis, which is commonly used to justify the implementation of the CDM. In this respect and in the framework of the Kyoto Protocol, even if the reduction of greenhouse gas emissions is a desirable objective, the reasons and the means undertaken to achieve clean technology transfer, scarcely hide a discrepancy between the objectives of the North and the actual needs of the final users from the South.

All these barriers finally stress the crucial role of attendant measures in the framework of technology transfer processes. Consequently, we highlight the necessity to adapt technologies to the diffusion conditions and to design institutions so as to take in charge technology transfer. This idea is close to the concept of Eco-Innovation introduced by Rennings (2000) who considers technological and institutional dynamics as interconnected processes. Technology transfer policies must therefore include an assessment of the needs of final users and encourage organisation structures which could transfer knowledge and know-how to final users as well as to local firms.

P. S. & O. P.[7]

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Appendix 1

We will proceed in three steps. The first step consists in defining the optimal p_s and the corresponding tax revenue when the southern country has to charge at least as high a tax rate as the northern country. The problem can be written as follows :

$$\max w(p_s, p_n) \text{ subject to } p_s \geq p_n .$$

This gives the following response function :

$$\overline{p_s}(\overline{p_n}) = \begin{cases} \frac{1}{2\alpha(b)}(\lambda + p_n) \ ; \ p_n \leq \lambda \\ p_n \ ; \ p_n \geq \lambda \end{cases}$$

and the maximised revenues:

$$w_1(\overline{p_n}(\overline{p_s}), \overline{p_n}) = \begin{cases} \frac{Ns}{\lambda}\left[\frac{pn + \lambda}{2\alpha(b)}\right]^2 \ ; \ p_n \leq \lambda \\ N_s p_n \ ; \ p_n \geq \lambda \end{cases}$$

The second step consists in defining the optimal p_s and the corresponding tax revenue when the southern country must undercut the northern country. The problem is written as follows:

$$\max w(p_s, p_n) \text{ subject to } p_s \leq p_n$$

This second problem gives the following response function:

$$\overline{p_s}(\overline{p_n}) = \begin{cases} p_n \ ; \ p_n \leq \lambda\theta \\ \frac{1}{2\alpha(b)}(\lambda\theta + p_n) \ ; \ p_n \geq \lambda\theta \end{cases}$$

and the maximised revenues:

$$w_2(\overline{p_n}(\overline{p_s}), \overline{p_n}) = \begin{cases} N_s p_n \ ; \ p_n \leq \lambda\theta \\ \frac{N_n}{\lambda}\left[\frac{p_n + \lambda\theta}{2\alpha(b)}\right]^2 \ ; \ p_n \geq \lambda\theta \end{cases}$$

The third step is to compare for all p_s the maximised revenues under these two different constrained problems in order to define the optimum for the unconstrained one. We do consider four different options:

(a) For $p_n \leq \min[\lambda, \lambda\theta]$, we compare :

$$\frac{N_s}{\lambda}\left[\frac{p_n + \lambda}{2\alpha(b)}\right]^2 - N_s p_n = N_s \frac{(p_n - \lambda)^2}{4\alpha(b)\lambda} \geq 0$$

As a result, from $p_n \leq \lambda$,

$$\overline{p_n}(\overline{p_s}) = \frac{1}{2\alpha(b)}(\lambda + p_n)$$

(b) For $p_n \geq \max[\lambda, \lambda\theta]$, we compare :

$$N_s p_n - \frac{N_n}{\lambda}\left[\frac{p_n + \lambda\theta}{2\alpha(b)}\right]^2 = -N_n \frac{(\lambda\theta - p_n)^2}{4\alpha(b)\lambda} \leq 0$$

As a result, from $p_n \geq \lambda\theta$,

$$\overline{p_n}(\overline{p_s}) = \frac{1}{2\alpha(b)}(\lambda\theta + p_n)$$

(c) If $\theta \geq 1$, then for $p_n \in [\lambda, \lambda\theta]$, we find that $w_1 = w_2$ and then $\overline{p_n}(\overline{p_s}) = p_n$.

(d) If $\theta \leq 1$ then for $p_n \in [\lambda, \lambda\theta]$, we compare :

$$\frac{N_s}{\lambda}\left[\frac{p_n + \lambda}{2\alpha(b)}\right]^2 - \frac{N_n}{\lambda}\left[\frac{p_n + \lambda\theta}{2\alpha(b)}\right]^2 = N_n(1-\theta)\frac{(\lambda^2\theta - p_n^2)}{4\alpha(b)\lambda}$$

As a result, from $\lambda \leq p_n \leq \lambda\theta$:

$$\overline{p_s}(\overline{p_n}) = \begin{cases} \frac{1}{2\alpha(b)}(\lambda + p_n) \ ; \ \lambda\theta \leq p_n \leq \lambda\sqrt{\theta} \\ \frac{1}{2\alpha(b)}(\lambda\theta + p_n) \ ; \ \lambda\theta \leq p_n \leq \lambda\sqrt{\theta} \end{cases}$$

Finally, considering these four options together, gives:

$$\text{for } \theta \leq 1, \overline{p_s}(\overline{p_n}) = \begin{cases} \frac{1}{2\alpha(b)}(\lambda + p_n) \ ; \ p_n \leq \lambda\sqrt{\theta} \\ \frac{1}{2\alpha(b)}(\lambda\theta + p_n) \ ; \ p_n \geq \lambda\sqrt{\theta} \end{cases}$$

$$\theta \geq 1, \overline{p_s}(\overline{p_n}) = \begin{cases} \frac{1}{2\alpha(b)}(\lambda + p_n) \ ; \ \overline{p_n} \leq \lambda \\ \overline{p_n} \ ; \ \lambda \leq \overline{p_n} \leq \frac{\lambda}{\theta} \\ \frac{1}{2\alpha(b)}(\frac{\lambda}{\theta} + p_n) \ ; \ \overline{p_n} \geq \frac{\lambda}{\theta} \end{cases}$$

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