Fondazione Eni Enrico Mattei

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NOTA DI LAVORO 78.2008

SEPTEMBER 2008

CCMP – Climate Change Modelling and Policy

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Summary

The paper considers a situation where two countries – the North and the South – use a non-traded polluting input to produce the goods for final consumption. The North is more efficient in both, production and abatement processes. The study compares the effects of the transfer of abatement technology by the North to the South under autarky with the free trade situation, assuming that the North pre-commits to an international protocol to keep the global pollution under a fixed level. The conditions under which either full or partial technology is transferred in autarky are determined. It is shown that under free trade no such transfer is possible. With trade even though the North wants a complete transfer of technology, the South refuses it.

Keywords: GHG Emissions, Mitigation, Technology Transfer, International Trade

JEL Classification: F18, F35, Q54, Q56

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I. Introduction

In the run-up to the decisive rounds of negotiations concerning a post-Kyoto agreement, there is much dispute about the emission-target levels as well as about the adequate policies to mitigate greenhouse gas emissions. Concerning the latter, one main controversial subject is the integration of developing countries.

The question regarding the emission targets is only blurredly indicated by the UN Framework Convention on Climate Change (UNFCCC), which is the fundament for the Kyoto Protocol. The Convention stipulates in its Article 2 that the ultimate objective of this Convention is to achieve the stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Concerning the adequate policies to mitigate greenhouse gas emissions, the UNFCCC assigned the main responsibility for combating climate change to the North. A way considered for also involving developing countries into the international abatement efforts is the transfer of cleaner technologies from industrialized to developing countries.

Technology transfer (see, e.g. Schelling (1992), IPCC (2007: 787)) as well as R&D see, e.g. Stern (2007)),[1] are regularly regarded as important strategies to combat global warming. Barrett (2006: 22) stresses that "R&D is especially needed to bring about substantial, long-term reductions in atmospheric concentrations of greenhouse gases". And Hoel and de Zeeuw (2008: 2) note that the international debate on climate protection agreements "circles to some extent around the question whether international treaties should focus on technology development rather than on emission reduction." Benedick (2001) proposes a portfolio of elements for a post-Kyoto plan, which draws heavily on the diffusion of technology. The included elements are emission reduction policies, government research development, technology standards and technology transfer.

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[1] However, the evaluations of policies supporting R&D are not positive throughout, see, e.g. Popp (2006) as well as Fischer and Newell (2007).

The IPCC (2000) points to the fact that one salient feature of technology transfer related to global climate change is that of scale. “Essentially all countries of the world could be involved in the process, and the number of technologies could easily run into the thousands” (IPCC (2000)). Furthermore, the whole world is expected to be the beneficiary of technology transfer.

Some strand of scientific literature addresses questions of how environmental policy influences the diffusion of improved technology. As Jaffe, Newell and Stavins (2002: 62) point out: “the long term nature of policy challenges such as that posed by the threat of global climate change makes it all the more important that we improve our understanding of the effects of environmental policy on innovation and diffusion of new technology.”

The flexible clean development mechanism (CDM) of the Kyoto scheme is seen as one important option to push the transfer of cleaner technologies. Haites, Duan and Seres (2006) note that although the CDM has no explicit technology transfer mandate, roughly one-third of all CDM-projects involve technology transfer. Dechezleprêtre, Glachant and Ménière (2008: 1275) even find that 43% of the 644 CDM projects they investigate are involving technology transfer and these projects are responsible for 84% of the expected annual CO_2 emission reductions. However, the host countries are very heterogeneous in their capability to attract technology transfer (Dechezleprêtre, Glachant and Ménière (2008: 1277)). Furthermore, Dechezleprêtre, Glachant and Ménière (2008: 1283) discover that technology transfers are more likely in large projects and that the probability of technology transfer is 50% higher when the project is developed in a subsidiary of an Annex 1 company; having an official credit buyer in the project also exerts a positive effect on transfer likeliness. Aslam (2001) investigates the role that the CDM could play in enhancing the effectiveness of north-south technology transfer. Millock (2002), in turn, argues that technology transfer can improve incentives for cost-effective emission reductions under bilateral CDM contracts when there is asymmetric information between the investor and the project-hosting party. Glachant and Ménière (2007) evaluate the ability of the CDM to yield the optimal diffusion path, when firms can adopt a cleaner technology simultaneously of sequentially. Since adaptation involves fixed cost endogenously decreasing with previous adaptation, inefficiencies are created and these are not properly addressed by the CDM. Due to these inefficiencies, Glachant and Ménière propose design improvements.

In this paper we will analyze technology transfers from industrialized countries towards the developing world in general equilibrium framework. We do not confine the analysis to a specific (technology) transfer scheme like the CDM, although the considered transfers could – in principle – be provided via CDM projects. We are interested in the role that international trade plays concerning the effects of technology transfer on global environmental protection. The role of trade in international technology transfer is a vivid field of research, as Saggi (2002) illustrates in his survey. However, our interest is focused on environmental protection technologies.

More precisely, in our analysis we will investigate and answer the following two research questions: 1) What are the determinants of the extent of technology transfer from the industrialized to the developing world? 2) Can technology transfer serve as an effective instrument to stabilize the global greenhouse gas emission level at a level that would prevent dangerous anthropogenic interference with the climate system, as claimed by the UNFCCC?

We will investigate these two questions by explicitly regarding the influence of international trade on the outcomes. As Brewer (2008: 1) points out: “there are some intersections that are especially problematic in the threats to the international climate and/or trade regimes, while there are others that offer opportunities for win-win outcomes”. By our analysis we intend to contribute to answering the more general question, under which circumstances international trade is beneficial concerning climate protection. As the World Bank (2007: 8) stresses: “Interestingly, the trade-environment debate has so far considered little in terms of global-scale environmental problems – climate change, declining biodiversity, the depletion of ocean fisheries, and the overexploitation of shared resources.”

Our framework developed to answer these questions takes account of two different scenarios: 1) the no-trade (“autarkic”) situation and 2) the setting where trade in two commodities takes place.[2] Thus, the basic setting, i.e. the distinction between autarky and free trade, is similar to that employed by Alpay (2000) and Mukherjee and Rübbelke (2006) in their Ricardian models. However, Alpay (2000) does not explicitly consider technology transfer from industrialized to developing countries. Like we do, Mukherjee and Rübbelke (2006) investigate the technology transfer from rich to poor countries, but in contrast to their study we include an immobile polluting input factor into the analysis which can be traded in none of both scenarios (autarky and free trade).[3] This polluting input can be regarded to be "electric power", whose production causes emissions of the greenhouse gas CO_2. Greenhouse gas mitigation could take place on the supplier side, e.g. by enhancing supply efficiency or increasing the proportion of biofuels in the production.

The technology transfer that we regard in our Ricardian model causes a mitigation of greenhouse gas emissions per production-output unit. Beladi, Jones and Marjit (1997) as well as Itoh and Tawada (2003) also employ a Ricardian approach to analyze technology transfer. Yet, Beladi, Jones and Marjit (1997) deal only with the transfer of production technologies and do not consider the change in the pollution level associated with the change in the production structure as an effect of trade. Therefore, in their framework, technology transfer from the North to the South is always beneficial. The study by Itoh and Tawada (2003) – which adopts the framework of Copeland and Taylor (1999) – investigating the technology-transfer issue and its interaction with pollution differs to ours due to differences in the assumptions about abatement commitments. Yang (1999) also considers the pollution mitigation effect of the technology transfer in the South, but ignores what Copeland and Taylor (2004, 2005) call the "scale effect", i.e. the expansion of the polluting industry. In contrast to our approach, in their analysis of endogenous technical change Copeland and Taylor (2005) as well as Takarada (2005) do not employ

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[2] As Ederington, Levinson and Minier (2004: 1) point out: "Trade liberalization can affect the environment through several mechanisms, such as interjurisdictional competition to lower standards, transfer of pollution abatement technology, cross-border spillovers, or changes to the overall scale of economies." They add that they consider the most direct effect of trade liberalization on the environment to be through the composition of industries. Reppelin-Hill (1999) provides an empirical analysis of the relationship between trade openness and the adoption/diffusion of clean technologies. Frankel and Rose (2005) investigate the effects of trade on local/regional air pollution (SO_2, NO_2, particulate matter).

[3] Jones and Marjit (2008) discuss how the feature that a country typically produces commodities which are non-tradeable in addtion to producing commodities for the world market, can be captured in trade models.

a Ricardian but a Heckscher-Ohlin framework and they do not address the technology transfer issue.

II. The Model

II.1 Preliminary Remarks

We suppose that - in line with Article 4 of the UNFCCC - the main obligation to combat climate change is assigned to the industrialized world and that - in line with the Kyoto Protocol - only the industrialized countries commit to pursue climate protection policies intending to stabilize the global climate. We allow for full as well as partly transfer of technologies in our framework.

II.2 Production of Goods

We assume that there are two countries, one is a developed country designated as North (*N*) and the other is an underdeveloped country designated as South (*S*). Each country produces two distinct private goods X_1 and X_2 which are used for final consumption. These goods are produced with the help of the primary input labour and an intermediate input X_3. X_3 is again produced by labour only. But the production of X_3 causes pollution by emitting carbon dioxide (CO_2). For simplicity, we assume that one unit of X_3 production emits one unit of CO_2. Thus X_3 is an impure public good as it has private good properties along with a public bad property by creating a negative externality all over the world. Suppose both the countries have the technology to abate pollution but the North has a better technology than the South. We assume that the i^{th} country abates the fraction ψ^i of the CO_2 emissions per unit of X_3 production using labour, where $\psi^i \in (0,1)$. So the final emission of CO_2 becomes $\phi^i = 1 - \psi^i$ per unit of X_3 production.

Both countries have identical labour endowments (L) along with full employment. From the full employment conditions we arrive at the following equations for the i^{th} country as:

$$L = a_1^i X_1^i + a_2^i X_2^i + a_3^i X_3^i + a_4^i \psi^i X_3^i \qquad (1)$$

and

$$X_3^i = a_{31}^i X_1^i + a_{32}^i X_2^i \ . \qquad (2)$$

Here a_j^i is the labour coefficient for the j^{th} good in the i^{th} country. It represents the amount of labour required to produce one unit of the j^{th} good in the i^{th} country, $\forall j = 1,2,3$ and $\forall$ $i = N, S$. a_4^i is the amount of labour required to abate the fraction ψ^i of one unit of CO_2 in the i^{th} country. Now a_{3k}^i is the amount of X_3 required as intermediate input to produce one unit of k^{th} good in the i^{th} country, $\forall$ $k = 1, 2$.

By substituting the value of X_3^i from equation (2) into the equation (1) we can derive the equation of the production possibility frontier (PPF) for the i^{th} country as:

$$L = [a_1^i + (a_3^i + a_4^i \psi^i) a_{31}^i] X_1^i + [a_2^i + (a_3^i + a_4^i \psi^i) a_{32}^i] X_2^i \ . \qquad (3)$$

We assume that the North is more efficient in the production of X_1, X_2, and X_3 and also in the abatement process than the South. So, all the labour coefficients of the North are less than the corresponding labour coefficients of the South. Furthermore, without loss of symmetry, we assume that in both countries the X_1 sector has a higher share of intermediate input in the total primary input requirement than the X_2 sector. This implies

$$\frac{a_{31}^i}{a_1^i + (a_3^i + a_4^i \psi^i) a_{31}^i} > \frac{a_{32}^i}{a_2^i + (a_3^i + a_4^i \psi^i) a_{32}^i} \text{ for all i = N, S.}$$

II.3 Utility Functions

Next we assume that both countries have identical welfare functions. Note that each country receives a positive utility from consuming X_1 and X_2. Yet the consumption of these goods inflicts a negative external effect on the society. This is because consumption of these goods demands production of X_3 which gives rise to global pollution. Thus in the process of consumption of X_1 and X_2, the society also has a disutility arising out of pollution. Accordingly we write the welfare function of the i^{th} country as:

$$U = U(X_1^i, X_2^i) - v(G) \qquad (4)$$

We consider $U(X_1^i, X_2^i)$ being a continuous, twice differentiable and strictly quasi-concave function over the domain $X_1^i, X_2^i \geq 0$. It also has the following properties: $U_1, U_2 > 0$ and $U_{11}, U_{22} < 0$ and $U_{12} = U_{21} = 0$. In equation (4), G represents the global pollution level. Thus, it holds:

$$G = \phi^N X_3^N + \phi^S X_3^S . \qquad (5)$$

Substituting the value of X_3^i from equation (2) into equation (5) we get:

$$G = \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + \phi^S (a_{31}^S X_1^S + a_{32}^S X_2^S) . \qquad (6)$$

We assume that the disutility function *v(G)* is a strictly increasing and convex function over the domain $X_1^i, X_2^i \geq 0$, that is $v^{/}(G) > 0$ and $v^{//}(G) > 0$.

In the following section we analyse how both countries determine their consumption levels simultaneously by maximising their respective welfare function subject to their labour input constraint.

II. 4 The Cournot-Nash Equilibrium

In the Cournot equilibrium the *i*th country maximises its welfare function given in equation (4) subject to the equation of the PPF as given in equation (3). So the problem for the *i*th country is written as:

$$\underset{\{X_1^i, X_2^i\}}{Max}\; U = U(X_1^i, X_2^i) - v(G)$$

subject to $L = [a_1^i + (a_3^i + a_4^i \psi^i) a_{31}^i] X_1^i + [a_2^i + (a_3^i + a_4^i \psi^i) a_{32}^i] X_2^i$,

where $G = \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + \phi^S (a_{31}^S X_1^S + a_{32}^S X_2^S)$.

We set up the Lagrange function for this constrained optimisation problem which becomes:

$$Max\ Z = U(X_1^i, X_2^i) - v(G) + \lambda\, [L - [a_1^i + (a_3^i + a_4^i \psi^i) a_{31}^i] X_1^i - [a_2^i + (a_3^i + a_4^i \psi^i) a_{32}^i] X_2^i] \qquad (7)$$

subject to $X_1^i, X_2^i, \lambda > 0$.

From equation (7) we get the following first-order conditions for the *i*th country:

$$\frac{\partial Z}{\partial X_1^i} = U_1 - v'(G)\varphi^i a_{31}^i - \lambda\, [a_1^i + (a_3^i + a_4^i \psi^i) a_{31}^i] = 0, \tag{8}$$

$$\frac{\partial Z}{\partial X_2^i} = U_2 - v'(G)\varphi^i a_{32}^i - \lambda\, [a_2^i + (a_3^i + a_4^i \psi^i) a_{32}^i] = 0, \tag{9}$$

$$\frac{\partial Z}{\partial \lambda} = L - [a_1^i + (a_3^i + a_4^i \psi^i) a_{31}^i] X_1^i - [a_2^i + (a_3^i + a_4^i \psi^i) a_{32}^i] X_2^i = 0. \tag{10}$$

Since the utility function is strictly quasi-concave and the disutility function is strictly convex which is also quasi-concave, the entire welfare function is strictly quasi-concave. This implies that the second-order condition for this constrained maximisation problem is also satisfied.

Solving equations (8) and (9), we get the optimum consumption levels of X_1 and X_2 for the i^{th} country. Let the optimum consumption levels be $X_1^i *$ and $X_2^i *$, respectively. Substituting these values of $X_1^i *$ and $X_2^i *$ into equation (2), we get the optimum production of the polluting good in the i^{th} country as $X_3^i *$. Thus the optimum pollution caused by the i^{th} country is $\phi^i X_3^i *$. Hence the optimum global pollution level becomes:

$$\overline{R} = \phi^N X_3^N * + \phi^S X_3^S *. \tag{11}$$

In the following sections we consider the different situations of technology transfer by the North to the South for better abatement along with the willingness of the North to transfer the technology and the acceptance of the South. Then we compare these situations under autarky with those under free trade.

II.5 Technology Transfer

We consider next the situation where the North commits within the framework of an international protocol to transfer its – more efficient – abatement technology to the South, such that the global pollution level does not go beyond $\overline{R}$ as given in equation (11), i.e. the optimum global pollution level before the transfer took place. We assume that the abatement technology is divisible and for the extent θ of technology transfer from the North to the South it holds that:

$$\theta > 0 \text{ and } \theta \in \left[\frac{\psi^S}{\psi^N}, 1\right]. \tag{12}$$

If $\theta = \frac{\psi^S}{\psi^N}$, this implies that the North does not offer any technology transfer to the South. If $\theta = 1$, then the North offers complete technology transfer and if $\theta \in \left(\frac{\psi^S}{\psi^N}, 1\right)$, then the North offers partial technology transfer to the South. Before the technology transfer takes place, the South could abate only ψ^S fraction of CO_2 emitted per unit of X_3 production using a_4^S units of labour. After receiving a better technology from the North it can abate an amount of $\theta\psi^N$ of CO_2 emission per unit of X_3 production using the same amount of labour. Due to the technology transfer the equation of the PPF of the South becomes:

$$L = [a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]X_1^S + [a_2^S + (a_3^S + a_4^S\theta\psi^N)a_{32}^S]X_2^S \tag{13}$$

Writing $[a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]$ as α^S and $[a_2^S + (a_3^S + a_4^S\theta\psi^N)a_{32}^S]$ as β^S we can rewrite equation (13) as:

$$L = \alpha^S X_1^S + \beta^S X_2^S \tag{14}$$

Note that even after the technology transfer took place, the following holds true:

$$\frac{a_{31}^S}{a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S} > \frac{a_{32}^S}{a_2^S + (a_3^S + a_4^S\theta\psi^N)a_{32}^S}$$

that is $\frac{a_{31}^S}{\alpha^S} > \frac{a_{32}^S}{\beta^S}$ (15)

Equation (15) implies that even after the technology transfer took place, the South still continues to have a higher share of intermediate input in total primary input in the X_1 sector than in the X_2 sector.

In a next step, we present the problem as one of sequential decision making. In the first stage, the North has to decide about its consumption levels of X_1 and X_2 and the extent of technology transfer, that is it has to choose X_1^N, X_2^N and θ. In the second stage, the

South observes X_1^N, X_2^N and θ and chooses its consumption levels X_1^S and X_2^S such that the global pollution level $G \leq \overline{R}$.

We solve this problem through backward induction method. The North first observes the reaction of the South to changes in its consumption of X_1, X_2 and θ and later on incorporates the reaction functions to solve for the optimum values of X_1, X_2 and θ. In the following sections we solve this problem separately for autarky and free trade.

II.5.1 Autarky Situation

Here the North first maximises the welfare function of the South and then derives its reaction functions. Substituting $i = S$ in equation (4) we write the welfare function of the South as:

$$U = U(X_1^S, X_2^S) - v(G)$$

Note that the value of G is not the same as in equation (6). This is because after the technology transfer the South abates $\theta\psi^N$ amount of CO_2 per unit of X_3 production. So the emission of the South becomes $(1 - \theta\psi^N)$. Thus the value of G now becomes:

$$G = \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + (1 - \theta\psi^N)(a_{31}^S X_1^S + a_{32}^S X_2^S)\,. \tag{16}$$

After substitution of the value of G from equation (16) into the welfare function of the South, the welfare maximization problem of the South can be written as:

Max $U = U(X_1^S, X_2^S) - v[\ \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + (1 - \theta\psi^N)(a_{31}^S X_1^S + a_{32}^S X_2^S)\ ]$

subject to $L = \alpha^S X_1^S + \beta^S X_2^S$.

Here the choice variables for the South are X_1^S and X_2^S as X_1^N, X_2^N and θ are already determined in stage one. So the South takes X_1^N, X_2^N and θ as given, while solving the problem. Now from equation (14) we can write:

$$X_2^S = \frac{L - \alpha^S X_1^S}{\beta^S}\,. \tag{17}$$

After substitution of the value of X_2^S from equation (17) into the welfare function of the South, the problem of the South becomes:

$$\text{Max}\, U = U\left(X_1^S, \frac{L-\alpha^S X_1^S}{\beta^S}\right) -$$

$$v\left[\, \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + (1-\theta\psi^N)\left\{a_{31}^S X_1^S + a_{32}^S \left(\frac{L-\alpha^S X_1^S}{\beta^S}\right)\right\}\right]. \qquad (18)$$

From equation (18) we get the following first-order condition for $X_1^S > 0$:

$$U_1 - U_2 \frac{\alpha^S}{\beta^S} - v'(1-\theta\psi^N)\alpha^S \left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right) = 0 \qquad (19)$$

In turn, from equation (19) we get the following second-order condition:

$$U_{11} + U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2 - v''(1-\theta\psi^N)^2 \alpha^{S^2} \left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)^2 < 0. \qquad (20)$$

Since U_{11}, $U_{22} < 0$ and $v^{//} > 0$, the expression in equation (20) is negative which implies that the second-order condition for the maximisation of the welfare of the South is satisfied.

From equations (19) and (20) we get the following lemma:

Lemma 1: *If* $G < \overline{R}$ *, then* $\frac{dX_1^S}{dX_1^N} < 0$, $\frac{dX_1^S}{dX_2^N} < 0$ *and* $\frac{dX_1^S}{d\theta} \overset{<}{\underset{>}{=}} 0$.

Proof: Totally differentiating equation (19) and substituting $dX_2^N = d\theta = 0$ we obtain:

$$\left[U_{11} + U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2 - v''(1-\theta\psi^N)^2 \alpha^{S^2} \left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)^2\right] dX_1^S =$$

$$\left[a_{31}^N \phi^N v''(1-\theta\psi^N)\alpha^S \left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\right] dX_1^N .$$

Thus, we get:

$$\frac{dX_1^S}{dX_1^N}=\frac{\left[a_{31}^N\phi^N v''(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\right]}{\left[U_{11}+U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2-v''(1-\theta\psi^N)^2\alpha^{S^2}\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)^2\right]}. \tag{21}$$

Note that the denominator of equation (21) is negative (see second-order condition (20)). From equation (15), in turn, we observe that the numerator of equation (21) is positive.

By totally differentiating equation (19) and substituting $dX_1^N = d\theta = 0$ we obtain:

$$\left[U_{11}+U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2-v''(1-\theta\psi^N)^2\alpha^{S^2}\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)^2\right]dX_1^S=$$

$$\left[a_{32}^N\phi^N v''(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\right]dX_2^N \tag{22}$$

Rearranging terms yields:

$$\frac{dX_1^S}{dX_2^N}=\frac{\left[a_{32}^N\phi^N v''(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\right]}{\left[U_{11}+U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2-v''(1-\theta\psi^N)^2\alpha^{S^2}\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)^2\right]} \tag{23}$$

The denominator of equation (23) is negative (see second-order condition (20)) and the numerator is positive (take account of equation (15)).

By total differentiation of equation (19) and substituting $dX_1^N = dX_2^N = 0$, we obtain:

$$\left[U_{11}+U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2-v''(1-\theta\psi^N)^2\alpha^{S^2}\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)^2\right]dX_1^S=$$

$$\alpha^S\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\left[\frac{U_2a_4^S\psi^N}{\beta^S}-\frac{v'(1-\theta\psi^N)a_{32}^Sa_4^S\psi^N}{\beta^S}-\psi^N v'-(1-\theta\psi^N)v''\psi^N X_3^S\right]d\theta. \tag{24}$$

So we get:

$$\frac{dX_1^S}{d\theta} = \frac{\alpha^S\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\left[\frac{U_2 a_4^S \psi^N}{\beta^S}-\frac{v'(1-\theta\psi^N)a_{32}^S a_4^S \psi^N}{\beta^S}-\psi^N v'-(1-\theta\psi^N)v''\psi^N X_3^S\right]}{\left[U_{11}+U_{22}\left(\frac{\alpha^S}{\beta^S}\right)^2-v''(1-\theta\psi^N)^2\alpha^{S^2}\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)^2\right]} \qquad (25)$$

Note that the denominator of equation (25) is negative due to the second-order condition as given in equation (20). In the numerator the term within (.) is positive as is evident from equation (15) but nothing can be said definitely about the sign of the term within [.]. The results of Lemma 1 can be explained intuitively. The North first chooses its output levels of X_1 and X_2 and also the extent of technology transfer.

The South, which is not committed to meet any emission target, chooses its output levels without taking into consideration that – from the North's point of view – the output levels should be such that the global pollution resulting from it does not go beyond the given limit $\overline{R}$.

However, if the North expands its production of any one good, then the South will reduce the production of X_1^S, because the negative externality (risen global pollution) exerted by the higher consumption level in the North makes own consumption of the strongly polluting good X_1 less attractive.

Yet, if the North increases the extent of technology transfer, then the South could increase the production of X_1 as well as of X_2, because the abatement of emissions has become less labour intensive and hence there is more labour input available for producing X_1 and X_2. Yet, depending on the shape of the South's welfare function, the production of X_1 may rise, remain constant or decrease. If the production of X_1 decreases, then it is obvious that the South will raise the production of X_2, since we assumed that inputs will be fully employed.

After incorporating the reaction functions of the South as given under Lemma 1, the North chooses its output levels and the level of technology transfer to maximise its welfare function. However, while doing this it has to satisfy some constraints like the full employment of labour and also the commitment that it should transfer technology in such a way that the global pollution level does not exceed $\overline{R}$. Also it must choose the extent of technology transfer that satisfies equation (12). Thus substituting $i = N$ in equation (3) we write the equation of the North's PPF as:

$$L = [a_1^N + (a_3^N + a_4^N \psi^N) a_{31}^N] X_1^N + [a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N] X_2^N . \qquad (26)$$

Let us denote $[a_1^N + (a_3^N + a_4^N \psi^N) a_{31}^N]$ as α^N and $[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]$ as β^N, so that we can rewrite equation (26) as:

$$L = \alpha^N X_1^N + \beta^N X_2^N . \qquad (27)$$

Rearranging of equation (27) yields:

$$X_2^N = \frac{L - \alpha^N X_1^N}{\beta^N} . \qquad (28)$$

After writing $i = N$ and substituting the value of X_2^N from equation (28) and the value of G from equation (16) into equation (4) we get the following welfare function of the North as:

$$U = U(X_1^N, \frac{L - \alpha^N X_1^N}{\beta^N}) -$$

$$v[\ \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + (1 - \theta\psi^N)\{a_{31}^S X_1^S + a_{32}^S (\frac{L - \alpha^S X_1^S}{\beta^S})\}] . \qquad (29)$$

The North maximises its welfare function given in equation (29) with respect to the following constraints:

$$\phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + (1 - \theta\psi^N)\{a_{31}^S X_1^S + a_{32}^S (\frac{L - \alpha^S X_1^S}{\beta^S})\} \le \overline{R} , \qquad (30)$$

$$\theta \ge \frac{\psi^S}{\psi^N} , \qquad (31)$$

$$\theta \le 1 . \qquad (32)$$

We set up the Lagrange function for this maximisation problem as:

$Z =$

$$U(X_1^N, \frac{L - \alpha^N X_1^N}{\beta^N}) - v[\ \phi^N (a_{31}^N X_1^N + a_{32}^N X_2^N) + (1 - \theta\psi^N)\{a_{31}^S X_1^S + a_{32}^S (\frac{L - \alpha^S X_1^S}{\beta^S})\}]$$

$$+ \quad \lambda_1[\overline{R} - \phi^N(a_{31}^N X_1^N + a_{32}^N X_2^N) - (1-\theta\psi^N)\{a_{31}^S X_1^S + a_{32}^S(\frac{L-\alpha^S X_1^S}{\beta^S})\}] + \quad \lambda_2[1 \quad - \quad \theta]$$

$$+\lambda_3[-\frac{\psi^S}{\psi^N} + \theta]. \tag{33}$$

Maximising equation (33) with respect to $X_1^N, \theta > 0$ we obtain the following first-order conditions:

$$\frac{\partial Z}{\partial X_1^N} = U_1 - U_2\frac{\alpha^N}{\beta^N} - (v' + \lambda_1)\left[\phi^N a_{31}^N - \phi^N a_{32}^N \frac{\alpha^N}{\beta^N} + (1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\frac{\partial X_1^S}{\partial X_1^N}\right] = 0 \tag{34}$$

$$\frac{\partial Z}{\partial \theta} = -(v' + \lambda_1)\left[-\psi^N X_3^S + (1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\frac{\partial X_1^S}{\partial \theta}\right] - \lambda_2 + \lambda_3 = 0 \tag{35}$$

$$\frac{\partial Z}{\partial \lambda_1} = \overline{R} - \phi^N(a_{31}^N X_1^N + a_{32}^N X_2^N) - (1-\theta\psi^N)\{a_{31}^S X_1^S + a_{32}^S(\frac{L-\alpha^S X_1^S}{\beta^S})\} \leq 0$$

$$\text{and}\,\lambda_1\frac{\partial Z}{\partial \lambda_1} = 0 \tag{36}$$

$$\frac{\partial Z}{\partial \lambda_2} = 1 - \theta \leq 0 \qquad \text{and}\,\lambda_2\frac{\partial Z}{\partial \lambda_2} = 0 \tag{37}$$

$$\frac{\partial Z}{\partial \lambda_3} = -\frac{\psi^S}{\psi^N} + \theta \leq 0 \qquad \text{and}\,\lambda_3\frac{\partial Z}{\partial \lambda_3} = 0 \tag{38}$$

The first order conditions enumerated in equations (34) to (38) help us to put forward our first proposition.

Proposition 1: *If the North offers to transfer an abatement technology to the South such that the global pollution level remains within the given limit* $\overline{R}$ *, then (i) it offers a partial technology transfer, i.e.* $\frac{\psi^S}{\psi^N} < \theta < 1$ *when* $G < \overline{R}$ *and the extent of technology transfer is*

$\theta^* = \frac{1}{\psi^N} \frac{\frac{\alpha^S X_1^S}{X_3^S} \varepsilon_1 \left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)}{1 + \frac{\alpha^S X_1^S}{X_3^S} \varepsilon_1 \left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)}$*, (ii) it always offers complete technology transfer i.e. $\theta = 1$ when $G = \overline{R}$ and if $G < \overline{R}$ then complete technology is transferred when* $\varepsilon_1 < \frac{\theta \psi^N}{1 - \theta \psi^N} \frac{X_3^S}{\alpha^S X_1^S} \frac{1}{\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)}$ *and (iii) it does not transfer any technology i.e. chooses* $\theta = \frac{\psi^S}{\psi^N}$*, if* $G < \overline{R}$ *and* $\varepsilon_1 > \frac{\theta \psi^N}{1 - \theta \psi^N} \frac{X_3^S}{\alpha^S X_1^S} \frac{1}{\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)}$*. Moreover the South does not accept any technology transfer offer from the North if* $G = \overline{R}$ *but if* $G < \overline{R}$ *then the South accepts the offer provided a necessary condition for acceptance* $\frac{v'}{U_2} \geq \frac{a_4^S}{\beta^S}$ *is fulfilled.*

Proof: see Appendix

The intuition of Proposition 1 is very simple. The North chooses partial technology transfer when G is less than $\overline{R}$ because at given output levels of the South, a better abatement technology leads to increased abatement in the South which increases the gap between the current global pollution level and $\overline{R}$. Then the North will take this advantage and will increase its production thereby increasing its welfare and taking the pollution level to $\overline{R}$. Thus it leaves no scope at all for the South to increase its production. The North does not make any offer of technology transfer, if $\varepsilon_1 > \frac{\theta \psi^N}{1 - \theta \psi^N} \frac{X_3^S}{\alpha^S X_1^S} \frac{1}{\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)}$. This is because if the responsiveness of the output in South to a change in the extent of technology transfer is very high, then a marginal change in the extent of technology transfer will increase abatement and in response will push up the production in South by a large extent. This will also increase pollution and the gap between pollution level and $\overline{R}$ closes. So the North cannot increase its production and enjoy higher welfare now as the pollution level can cross $\overline{R}$. So in this situation it will take the decision of not transferring any abatement technology to the South. Again, if $\varepsilon_1 < \frac{\theta\psi^N}{1-\theta\psi^N}\frac{X_3^S}{\alpha^S X_1^S}\frac{1}{\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)}$, then North will offer complete technology transfer to the South if $G < \overline{R}$. This is because here if North makes any technology transfer by marginal amount, then the output in the South will not change (if $G = \overline{R}$) or it will increase by a much smaller amount when $G < \overline{R}$. So the North observes that if it transfers its entire abatement technology to the South, abatement will increase and global pollution will fall. There will be a gap between the pollution level and $\overline{R}$ which can be filled up by the North itself by increasing its production thereby increasing its welfare too.

It is interesting to note that when $G = \overline{R}$, although the North wants to make complete technology transfer to the South still the latter will never accept this offer from the former in this situation. This is because the South observes that it cannot increase its output even though the North transfers its abatement technology. So at given output levels there will be now more abatement which will make the global pollution constraint non-binding. This will allow the North to expand its production and increase the pollution level to make the pollution constraint binding. Thus the North gains from increase in consumption of goods. Yet, the South cannot gain as it cannot increase its production but on the contrary it will suffer a loss due to the increase in the global pollution level. But if $G < \overline{R}$, then South will accept the technology transfer offer from the North as long as $\frac{v'}{U_2} \geq \frac{a_4^S}{\beta^S}$. Note that $\frac{v'}{U_2}$ indicates the ratio of marginal loss to South resulting from pollution to the marginal benefit arising out of consumption of X_2. In this situation a transfer of technology will allow the South to increase its production of X_1 and reduce the production of X_2. So the marginal benefit from consumption of X_2 increases due to the assumption of diminishing marginal utility. But increase of production of X_1 increases the pollution level for which it has to suffer a loss. If $\frac{v'}{U_2} < \frac{a_4^S}{\beta^S}$ then the South will not accept the technology transfer by the North since the marginal benefit arising out from X_2 outweighs the loss arising from increase in pollution. So it will accept the offer of technology transfer only when the ratio of marginal loss to marginal benefit is at least as high as $\frac{a_4^S}{\beta^S}$.

II.5.2 Free Trade Situation

The countries now engage themselves in free trade. Since both the countries have identical labour endowments so the only basis for trade here is the difference in production technologies. Following Ricardian theory of Comparative Advantage, we assume that the North has a comparative advantage in the production of X_2 and the South has a comparative advantage in the production of X_1. This means that the labour cost of producing one unit of X_2 relative to X_1 is lower in North than in South (See Daerdorff, 2005)[4]. So from equation (3) we have:

$$\frac{[a_1^N + (a_3^N + a_4^N \psi^N) a_{31}^N]}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} > \frac{[a_1^S + (a_3^S + a_4^S \psi^S) a_{31}^S]}{[a_2^S + (a_3^S + a_4^S \psi^S) a_{32}^S]} \tag{46}$$

Let us take the international price ratio of X_1 relative to X_2 as $\frac{p_1}{p_2}$. So we must have:

$$\frac{[a_1^N + (a_3^N + a_4^N \psi^N) a_{31}^N]}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} > \frac{p_1}{p_2} > \frac{[a_1^S + (a_3^S + a_4^S \psi^S) a_{31}^S]}{[a_2^S + (a_3^S + a_4^S \psi^S) a_{32}^S]} \tag{47}$$

Let us call $\frac{p_1}{p_2}$ as $\frac{1}{p}$ so that $p = \frac{p_2}{p_1}$. Therefore equation (47) is written as:

$$\frac{[a_1^N + (a_3^N + a_4^N \psi^N) a_{31}^N]}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} > \frac{1}{p} > \frac{[a_1^S + (a_3^S + a_4^S \psi^S) a_{31}^S]}{[a_2^S + (a_3^S + a_4^S \psi^S) a_{32}^S]} \tag{48}$$

According to the Ricardian theory after trade a country completely specialises in the production of that commodity in which it has a comparative advantage. This implies that after trade North produces only X_2 and the South produces only X_1.

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[4] Assume that the price of the intermediate input i.e. X_3 is unity.

So putting $i = N$ and $X_1 = 0$ in equation (3) we get the production of X_2 in North as:

$$X_2^N = \frac{L}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} \tag{49}$$

Similarly putting $i = S$ and $X_2 = 0$ in equation (3) we get the production of X_1 in South as:

$$X_1^S = \frac{L}{[a_1^S + (a_3^S + a_4^S \psi^S) a_{31}^S]} \tag{50}$$

Let $\tilde{X}_1^i$ and $\tilde{X}_2^i$ denote the consumption of X_1 and X_2 respectively after trade in the ith country, $\forall\ i = N, S$.

So the budget constraint for the North becomes:

$$\tilde{X}_1^N + p\tilde{X}_2^N = p\frac{L}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} \tag{51}$$

Similarly the budget constraint of the South is written as:

$$\tilde{X}_1^S + p\tilde{X}_2^S = \frac{L}{[a_1^S + (a_3^S + a_4^S \psi^S) a_{31}^S]} \tag{52}$$

Since X_1 is produced in the South only so the consumption of X_1 by the North and the South must equal the total X_1 production in the world. Thus we get the world market equilibrium condition for X_1 as:

$$\tilde{X}_1^S(p) + \tilde{X}_1^N(p) = \frac{L}{[a_1^S + (a_3^S + a_4^S \psi^S) a_{31}^S]} \tag{53}$$

Similarly we get a world market equilibrium condition for X_2 as:

$$\tilde{X}_2^S(p) + \tilde{X}_2^N(p) = \frac{L}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} \tag{54}$$

Thus after trade the level of pollution in the world becomes:

$$\text{R} = \phi^N a_{32}^N X_2^N + \phi^S a_{31}^S X_1^S \tag{55}$$

The equation (55) leads to Lemma 2.

Lemma 2: $R > \overline{R}$

Proof: The Ricardian theory of trade highlights the beneficial role of free trade over autarky in gains from trade by proposing that the world production and consumption of goods rises after trade as trade leads to an efficient allocation of resources. So the production of X_1 and X_2 in the world increases after trade. This leads to an increased production of the polluting intermediate input X_3 in the world. So the global pollution level after trade definitely exceeds the same before trade.

The result of Lemma 1 increases the urgency of the abatement technology transfer to keep the global pollution level at $\overline{R}$. So let θ be the extent of abatement technology that the North can transfer to the South. Here also the choice of θ is subject to the constraint as given in equation (12).

Thus after technology transfer the level of pollution in the world becomes:

$$\begin{aligned} R &= \phi^N a_{32}^N X_2^N + (1-\theta\psi^N) a_{31}^S X_1^S \\ &= \phi^N a_{32}^N [\tilde{X}_2^N(p) + \tilde{X}_2^S(p)] + (1-\theta\psi^N) a_{31}^S [\tilde{X}_1^N(p) + \tilde{X}_1^S(p)] \qquad (56) \end{aligned}$$

From equation (53) we get the following lemma:

Lemma 3: $\dfrac{dp}{d\theta} > 0$.

Proof: Now differentiating both sides of equation (53) with respect to θ we get:

$$\frac{d\tilde{X}_1^S}{dp}\frac{dp}{d\theta} + \frac{d\tilde{X}_1^N}{dp}\frac{dp}{d\theta} = -\frac{a_4^S \psi^N a_{31}^S L}{[a_1^S + (a_3^S + a_4^S\psi^S)a_{31}^S]^2}$$

That is
$$\frac{dp}{d\theta} = -\frac{a_4^S \psi^N a_{31}^S L}{[a_1^S + (a_3^S + a_4^S\psi^S)a_{31}^S]^2} \frac{1}{\dfrac{d\tilde{X}_1^S}{dp} + \dfrac{d\tilde{X}_1^N}{dp}} \qquad (57)$$

Note that in equation (57) the term $\left(\dfrac{d\tilde{X}_1^S}{dp} + \dfrac{d\tilde{X}_1^N}{dp}\right)$ is negative by the Walrasian stability condition of the international equilibrium. Thus $\dfrac{dp}{d\theta} > 0$.

The result of Lemma 3 can be intuitively explained. When the North transfers technology to the South then the abatement increases in the South and it becomes more efficient in the production of X_1. As a result the production of X_1 increases and the price of it falls in the world market. In other words, the relative price of X_2 increases.

The welfare function of the North leads to the second proposition:

Proposition 2: *Under free trade the North will always offer full abatement technology to the South as the global pollution level is higher than the level specified in the protocol. On the other hand the South will never accept this technology transfer from the North.*

Proof: From equation (4) we get the welfare function of the North under free trade after putting $i = N$ as:

$$U = U(\tilde{X}_1^N, \tilde{X}_2^N) - v(\overline{R}) \tag{58}$$

From equation (51) we can write $\tilde{X}_2^N = \left(p \dfrac{L}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} - \tilde{X}_1^N \right) \dfrac{1}{p}$ and substituting it into equation (58) we have:

$$U = U\left[\tilde{X}_1^N, \left(p \frac{L}{[a_2^N + (a_3^N + a_4^N \psi^N) a_{32}^N]} - \tilde{X}_1^N \right) \frac{1}{p} \right] - v(R) \tag{59}$$

Maximising equation (59) with respect to $\tilde{X}_1^N$ and θ we get the following first order conditions:

$$\frac{\partial U}{\partial \tilde{X}_1^N} = U_1 - \frac{U_2}{p} = 0 \tag{60}$$

and $$\frac{\partial U}{\partial \theta} = \frac{dp}{d\theta} \left[\frac{d\tilde{X}_1^N}{dp} \left(U_1 - \frac{U_2}{p} \right) - \frac{U_2}{p^2} \left(- \tilde{X}_1^N \right) \right] \tag{61}$$

Using the first order condition given in equation (60) we can rewrite equation (61) as:

$$\frac{\partial U}{\partial \theta} = \frac{dp}{d\theta} \left[\frac{U_2}{p^2} \left(\tilde{X}_1^N \right) \right]$$

Using Lemma 3, we get $\dfrac{\partial U}{\partial \theta} > 0$, i.e. the marginal benefit that accrues to the North after transferring technology to the South is positive. Hence, the North will transfer its entire abatement technology to the South.

Rewriting equation (4) putting i = S the welfare function of the South is obtained as follows:

$$U = U(\tilde{X}_1^S, \tilde{X}_2^S) - v(\overline{R}) \tag{62}$$

Modifying equation (52) after incorporating the technological parameter θ we get:

$$\tilde{X}_1^S + p\tilde{X}_2^S = \frac{L}{[a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]} \tag{63}$$

Now South will maximise its welfare function as given in equation (62) using equation (63) as the constraint. From equation (63) we can write $\tilde{X}_1^S = \frac{L}{[a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]} - p\tilde{X}_2^S$ and substituting it into equation (62) we have:

$$U = U\left(\frac{L}{[a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]} - p\tilde{X}_2^S, \tilde{X}_2^S\right) - v(\overline{R}) \tag{64}$$

Maximising equation (64) with respect to $\tilde{X}_2^S$ and θ we get the following first order conditions:

$$\frac{\partial U}{\partial \tilde{X}_2^S} = U_1(-p) + U_2 = 0 \tag{65}$$

$$\frac{\partial U}{\partial \theta} = \frac{dp}{d\theta}\left[\frac{d\tilde{X}_2^S}{dp}\left(U_1(-p) + U_2\right) - U_1\tilde{X}_2^S\right] - \frac{La_4^S\psi^N a_{31}^S U_1}{[a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]^2} \tag{66}$$

Using the first order condition given in equation (65) we can rewrite equation (66) as:

$$\frac{\partial U}{\partial \theta} = \frac{dp}{d\theta}\left[-U_1\tilde{X}_2^S\right] - \frac{La_4^S\psi^N a_{31}^S U_1}{[a_1^S + (a_3^S + a_4^S\theta\psi^N)a_{31}^S]^2}$$

Using the result of Lemma 3, we get $\frac{\partial U}{\partial \theta} < 0$, i.e. the marginal benefit that accrues to the South after receiving technology from the North is negative. Hence, the South will never accept any abatement technology from the North. □

The intuition behind this proposition is very clear. The results of Lemma 3 point out that if there is a marginal technology transfer from the North to the South then it will raise the relative price of X_2 to X_1 in the international market. Since North is the exporter of X_2 so it gains from this technology transfer as it shifts the terms of trade in its favour. Due to this favourable 'terms of trade' effect the North will always be inclined to transfer its full abatement technology to the South. But as the terms of trade goes against the South so it has nothing to gain from this technology transfer. Hence it will not accept the offer of the North.

III. Conclusions

Global warming is one of the major threats to our planet. Combat of climate change cannot be effectively conducted by individual countries alone, but requires global efforts. However, developing countries are reluctant to commit to climate protection efforts or greenhouse gas abatement in an international protocol. This is due to the fact that these countries currently face also other and more immediate threats like hunger and diseases. Furthermore, they point to the fact that global warming is mainly caused by greenhouse gas emissions stemming from industrialized countries and therefore, it is mainly these countries' responsibility to combat this threat.

One way to include developing countries in international climate protection efforts nevertheless, is to offer transfers to these countries. In our study we focused on transfers in the shape of (more efficient abatement) technology. Our aim was to analyze the interdependencies between technology transfer, climate protection and trade.

We employed a framework where two regions, viz. the North and the South, are producing two commodities which demand the use of a polluting input apart from the primary input labour. The North, which basically resembles the features of industrialized countries, is efficient in the production of the goods and as well as in the abatement of the pollution associated with the production process. There is a global body (international protocol) which regulates the global pollution level by fixing up an upper limit. The North has committed to keep the global pollution level under control. In order to meet the emission target, it faces two options: 1.) reducing own emissions and 2.) transferring efficient abatement technology (either partially or in fully) in the polluting non-traded sector (like energy production) to the South. The South has been assumed to have comparative advantage in production of the commodity that intensively uses the non-traded commodity.

Regarding two different situations, i.e. the autarky case and the free trade case, we analyze the choice of the North and the induced consequences. The distinction between both settings is employed in order to disclose the impacts of rising trade openness.

In the autarky case we see that the North may transfer either complete or partial technology or it may even stay away from making any transfer. Even though the technology is transferred free of cost, the South may not always benefit.

In contrast, under free trade and complete specialisation although the North always has incentive to offer complete transfer of its technology to the South, the South has no incentive to accept it. Consequently, our analysis provides the new insight that free trade leads to coordination failure between the countries concerning the efficient technology use and ends up in a suboptimal global equilibrium. The world will finally face a pollution level that is higher than the limit specified by the international protocol.

Thus, we can draw the conclusion that globalisation or increased trade openness tends to weaken the role technology transfer could play in raising global climate protection levels. However, we have to note that our analysis is based on some restrictive assumptions. Relaxation of these might lead to variances in the results. The modification of the assumptions about the commodity-pollution structures in the individual countries' production processes could change the results according to the effects of trade openness. Furthermore, the assumptions of complete specialisation and costless technology transfers belong to the limiting parts of the paper. Future research could address these limitations, e.g. by comparing the effects of abatement technology transfer with those of a 'mix' of abatement and production technology transfer.

Appendix

Proof of Proposition 1:

Case I

Due to equations (36), (37) and (38), let us assume that $\lambda_1 = \lambda_2 = \lambda_3 = 0$. This implies at equilibrium $G < \overline{R}$ and $\frac{\psi^S}{\psi^N} < \theta < 1$, that is the North chooses partial technology transfer when the global pollution constraint is non-binding. So from equation (35) we get:

$$\left[(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\frac{\partial X_1^S}{\partial\theta}\right] = \psi^N X_3^S \tag{39}$$

Let us define: $\varepsilon_1 = \frac{dX_1^S}{d\theta}\frac{\theta}{X_1^S}$. It measures the responsiveness in the output of X_1 in the South due to a change in the extent of technology transfer by the North.

Thus from equation (39) we obtain:

$$\left[\frac{(1-\theta\psi^N)}{\theta}\frac{\alpha^S X_1^S}{X_3^S}\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)\varepsilon_1\right] = \psi^N \tag{40}$$

From equation (40) we get $\theta^* = \frac{1}{\psi^N}\frac{\frac{\alpha^S X_1^S}{X_3^S}\varepsilon_1\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)}{1+\frac{\alpha^S X_1^S}{X_3^S}\varepsilon_1\left(\frac{a_{31}^S}{\alpha^S}-\frac{a_{32}^S}{\beta^S}\right)}$.

Case II: Now suppose $\lambda_1 > 0$ and $\lambda_2 = \lambda_3 = 0$. This means that $G = \overline{R}$ and $\frac{\psi^S}{\psi^N} < \theta < 1$.

In other words, north transfers partial technology when the pollution constraint is strictly binding.

From equation (35) we get:

$$\frac{\partial Z}{\partial\theta} = (v' + \lambda_1)\psi^N X_3^S . \tag{41}$$

Note that from Lemma 1 we already have $\frac{\partial X_1^S}{\partial \theta}$ = 0 when $G = \overline{R}$. So from equation (41) we see that $\frac{\partial Z}{\partial \theta} > 0$. In this situation the North will always choose complete technology transfer, that is θ = 1. Yet, we have partial technology transfer by assumption. Hence this case is inconsistent.

Case III: Let us assume that λ_1 = λ_2 = 0 and λ_3 > 0. This means at equilibrium $G < \overline{R}$ and $\frac{\psi^S}{\psi^N} = \theta < 1$, so North does not transfer any technology to the South when the global pollution level is below $\overline{R}$. Consequently, from equation (35) and for $\frac{\partial Z}{\partial \theta} = 0$ we get:

$$\left[(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\frac{\partial X_1^S}{\partial \theta}\right] > \psi^N X_3^S$$

or $\left[\frac{(1-\theta\psi^N)}{\theta}\frac{\alpha^S X_1^S}{X_3^S}\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\varepsilon_1\right] > \psi^N$

or $\varepsilon_1 > \frac{\theta\psi^N}{1-\theta\psi^N}\frac{X_3^S}{\alpha^S X_1^S}\frac{1}{\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)}$.

Case IV: Now let us take λ_1 > *0,* λ_2 = and λ_3 > 0. Therefore, at equilibrium $G = \overline{R}$ and $\frac{\psi^S}{\psi^N} = \theta < 1$, which implies that when the pollution constraint is binding the North does not choose to transfer any technology. Thus it holds due to equation (35):

$\frac{\partial Z}{\partial \theta} = (v' + \lambda_1)\psi^N X_3^S + \lambda_3$. Using Lemma 1 we have $\frac{\partial X_1^S}{\partial \theta}$ = 0, when $G = \overline{R}$. Here we also observe that $\frac{\partial Z}{\partial \theta} > 0$. In this situation the North will always choose complete technology transfer, that is θ = 1. However, we already have no technology transfer at equilibrium by assumption. So this case is inconsistent and we cannot have this type of equilibrium.

Case V: Let us now consider that $\lambda_1 = 0$, $\lambda_2 > 0$ and $\lambda_3 = 0$. This means now at equilibrium we have $G < \overline{R}$ and $\frac{\psi^S}{\psi^N} < \theta = 1$ such that North chooses complete technology transfer when the pollution level is below the limit as specified in the protocol.

Again from equation (35) and for $\frac{\partial Z}{\partial \theta} = 0$ we get:

$$\left[(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\frac{\partial X_1^S}{\partial \theta}\right] < \psi^N X_3^S$$

or $$\left[\frac{(1-\theta\psi^N)}{\theta}\frac{\alpha^S X_1^S}{X_3^S}\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\varepsilon_1\right] < \psi^N$$

or $$\varepsilon_1 < \frac{\theta\psi^N}{1-\theta\psi^N}\frac{X_3^S}{\alpha^S X_1^S}\frac{1}{\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)}.$$

Case VI: Let us suppose that $\lambda_1 > 0$, $\lambda_2 > 0$ and $\lambda_3 = 0$. So at equilibrium we have $G = \overline{R}$ and $\frac{\psi^S}{\psi^N} < \theta = 1$, that is the North transfers complete technology when the pollution constraint is fully binding. So from equation (35) we get the following condition:

$$(v' + \lambda_1)\psi^N X_3^S - \lambda_2 = 0 \tag{42}$$

Now from equation (42) we observe that the signs of the given parameters can satisfy this equation. Hence this case is consistent and can be classified as an equilibrium outcome.

From equation (18) we obtain the following welfare function of the South:

$$U = U\left(X_1^S, \frac{L-\alpha^S X_1^S}{\beta^S}\right) -$$

$$v\left[\phi^N(a_{31}^N X_1^N + a_{32}^N X_2^N) + (1-\theta\psi^N)\left\{a_{31}^S X_1^S + a_{32}^S\left(\frac{L-\alpha^S X_1^S}{\beta^S}\right)\right\}\right] \tag{43}$$

Differentiating equation (43) with respect to θ we find:

$$\frac{dU}{d\theta} = \frac{dX_1^S}{d\theta}\left[U_1 - U_2\frac{\alpha^S}{\beta^S} - v'(1-\theta\psi^N)\alpha^S\left(\frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)\right] - U_2\left[a_4^S\psi^N\left(\frac{a_{31}^S X_1^S}{\beta^S} + \frac{a_{32}^S X_2^S}{\beta^S}\right)\right]$$

$$+v'\psi^N X_3^S \tag{44}$$

By using the first-order condition of the South given in equation (19) as well as equation (2), we can write equation (44) as:

$$\frac{dU}{d\theta} = -U_2\, a_4^S \psi^N \frac{X_3^S}{\beta^S} + v'\psi^N X_3^S$$

$$= \psi^N X_3^S U_2 \left(\frac{v'}{U_2} - \frac{a_4^S}{\beta^S} \right) \tag{45}$$

If $G < \overline{R}$, then $\frac{dU}{d\theta} \geq 0$, if and only if $\frac{v'}{U_2} \geq \frac{a_4^S}{\beta^S}$. Yet, if $G = \overline{R}$, then $v' = 0$ which implies $\frac{dU}{d\theta} < 0$. □

References

Alpay, S. (2000): Does Trade Always Harm the Global Environment? A Case for Positive Interaction, *Oxford Economic Papers*, 52, 272-288.

Aslam, M.A. (2001): Technology Transfer under the CDM – Materializing the Myth in the Japanese Context?, *Climate Policy*, 1, 451-464.

Barrett, S. (2006): Climate Treaties and “Breakthrough” Technologies, *American Economic Review*, 96, 22-25.

Beladi, H.; Jones, R.W. and Marjit, S. (1997): Technology for Sale, *Pacific Economic Review*, 2, 187-196.

Benedick, R.E. (2001): Striking a New Deal on Climate Change, *Issues in Science and Technology Online*, Fall 2001.

Brewer, T.L. (2008): *The Trade and Climate Change Joint Agenda*, CEPS Working Document No. 295, Centre for European Policy Studies, Brussels.

Copeland, B. and Taylor, M.S. (1999): Trade, Spatial Separation and the Environment, *Journal of International Economics*, 47, 137-168.

Copeland, B. and Taylor, M.S. (2004): Trade, Growth and Environment, *Journal of Economic Literature*, 42, 7-71.

Copeland, B. and Taylor, M.S. (2005): Free Trade with Global Warming: A Trade Theory View of Kyoto Protocol, *Journal of Environmental Economics and Management,* 49, 205-234.

Dechezleprêtre, A.; Glachant, M. and Ménière, Y. (2008): The Clean Development Mechanism and the International Diffusion of Technologies: An Empirical Study, *Energy Policy*, 36, 1273-1283.

Ederington, J.; Levinson, A. and Minier, J. (2004): Trade Liberalization and Pollution Havens, *Advances in Economic Analysis & Policy*, 4, 1-22.

Fischer, C. and Newell, R.G. (2008): Environmental and Technology Policies for Climate Mitigation, *Journal of Environmental Economics and Management*, 55, 142-162.

Frankel, J.A. and Rose, A.K. (2005): Is Trade Good or Bad for the Environment? Sorting Out the Causality, *Review of Economics and Statistics*, 87, 85-91.

Glachant, M. and Ménière, Y. (2007): *Kyoto Project Mechanism and Technology Diffusion*, Working Paper, CERNA, Paris.

Haites, E.; Duan, M. and Seres, S. (2006): *Technology Transfer by CDM Projects*, *Climate Policy*, 327-344.

Hoel, M. and de Zeeuw, A. (2008): *Can a Focus on Breakthrough Technologies Improve Stability of International Environmental Agreements?*, paper presented at the workshop “The Environment, Technology and Uncertainty” of the Ragnar Frisch Centre for Economic Research, Oslo.

IPCC (2000): *Methodological and Technological Issues in Technology Transfer*, Cambridge University Press, Cambridge.

IPCC (2007): *Climate Change 2007 - Mitigation of Climate Change*, Cambridge University Press, Cambridge.

Itoh, A. and Tawada, M. (2003): Environment, Trade and the Welfare Gains from the Transfer of Pollution Abatement Technology, *Papers in Regional Science*, 82, 519-534.

Jaffe, A.B.; Newell, R.G. and Stavins, R.N. (2002): Environmental Policy and Technological Change, *Environmental and Resource Economics*, 22, 41-69.

Jones, R.W. and Marjit, S. (2008): Competitive Trade Models and Real World Features, *Economic Theory*, forthcoming.

Millock, K. (2002): Technology Transfers in the Clean Development Mechanism: an Incentive Issue, *Environment and Development Economics*, 7, 449-466.

Mukherjee, V. and Rübbelke, D.T.G. (2006): *Global Climate Change, Technology Transfer and Trade with Complete Specialization*, Nota di Lavoro 114.2006, Fondazione Eni Enrico Mattei, Milan.

Popp, D. (2006): R&D Subsidies and Climate Policy: Is There a “Free Lunch”?, *Climatic Change*, 77, 311-341.

Reppelin-Hill, V. (1999): Trade and Environment: An Empirical Analysis of the Technology Effect in the Steel Industry, *Journal of Environmental Economics and Management*, 38, 283-301.

Saggi, K. (2002): Trade, Foreign Direct Investment, and International Technology Transfer: A Survey, *World Bank Research Observer*, 17, 191-235.

Schelling, T.C. (1992): Some Economics of Global Warming, *American Economic Review*, 82, 1-14.

Stern, N. (2007): *The Economics of Climate Change – The Stern Review*, Cambridge University Press, Cambridge.

Takarada, Y. (2005): Transboundary Pollution and the Welfare Effects of Technology Transfers, *Journal of Economics*, 85, 251-275.

World Bank (2007): *International Trade and Climate Change: Economic, Legal, and Institutional Perspectives*, Washington DC.

Yang, Z. (1999): Should the North Make Unilateral Technology Transfers to the South? North-South Cooperation and Conflicts in Responses to Global Climate Change, *Resource and Energy Economics*, 21, 67-87.

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