Rübbelke, Dirk T. G.; Mukherjee, Vivekananda; Sanyal, Tilak

Working Paper
Technology transfer in the non-traded sector as a means to combat global warming

Nota di Lavoro, No. 78.2008

Provided in Cooperation with:
Fondazione Eni Enrico Mattei (FEEM)

Suggested Citation: Rübbelke, Dirk T. G.; Mukherjee, Vivekananda; Sanyal, Tilak (2008): Technology transfer in the non-traded sector as a means to combat global warming, Nota di Lavoro, No. 78.2008, Fondazione Eni Enrico Mattei (FEEM), Milano

This Version is available at:
http://hdl.handle.net/10419/53352

Terms of use:
Documents in EconStor may be saved and copied for your personal and scholarly purposes. You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.
Technology Transfer in the Non-traded Sector as a Means to Combat Global Warming
Vivekananda Mukherjee, Dirk T.G. Rübbelke and Tilak Sanyal
NOTA DI LAVORO 78.2008

SEPTEMBER 2008
CCMP – Climate Change Modelling and Policy

Vivekananda Mukherjee and Tilak Sanyal, Department of Economics, Jadavpur University
Dirk T.G. Rübbelke, Center for International Climate and Environmental Research (CICERO)

This paper can be downloaded without charge at:

The Fondazione Eni Enrico Mattei Note di Lavoro Series Index:
http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm

Social Science Research Network Electronic Paper Collection:
http://ssrn.com/abstract=1272988

The opinions expressed in this paper do not necessarily reflect the position of Fondazione Eni Enrico Mattei
Corso Magenta, 63, 20123 Milano (I), web site: www.feem.it, e-mail: working.papers@feem.it
Technology Transfer in the Non-traded Sector as a Means to Combat Global Warming

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

Address for correspondence:

Dirk T.G. Rübbelke
CICERO
Gaustadalléen 2
0349 Oslo
Norway
E-mail: dirk.ruebbelke@cicero.uio.no
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.

\(^1\) 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 CO₂ 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 or 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 CO₂. 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

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 (SO₂, NO₂, particulate matter).
³ Jones and Marjit (2008) discuss how the feature that a country typically produces commodities which are non-tradeable in addition 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 $\psi$ of the CO$_2$ emissions per unit of $X_3$ production using labour, where $\psi' \in (0,1)$. So the final emission of CO$_2$ becomes $\phi = 1 - \psi$ 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:
Here $a^i_j$ 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 $\forall i = N, S$. $a^i_j$ is the amount of labour required to abate the fraction $\psi'$ of one unit of CO$_2$ in the $i^{th}$ country. Now $a^i_{3k}$ 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 $X^i_3$ from equation (2) into the equation (1) we can derive the equation of the production possibility frontier (PPF) for the $i^{th}$ country as:

$$L = a^i_1 X^i_1 + a^i_2 X^i_2 + a^i_3 X^i_3 + a^i_4 \psi' X^i_3$$

(1)

and

$$X^i_3 = a^i_{31} X^i_1 + a^i_{32} X^i_2$$

(2)

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:
We consider $U(X_1', X_2')$ being a continuous, twice differentiable and strictly quasi-concave function over the domain $X_1', X_2' \geq 0$. 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:

$$G = \phi^N X_3^N + \phi^S X_3^S.$$  

(5)

Substituting the value of $X_3'$ from equation (2) into equation (5) we get:

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

(6)

We assume that the disutility function $v(G)$ is a strictly increasing and convex function over the domain $X_1', X_2' \geq 0$, 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:

$$\text{Max}_{(X_1, X_2)} U = U(X_1', X_2') - v(G)$$

subject to $L = [a_{11} + (a_i^1 + \alpha_i^1 \psi') a_{11}'] X_1' + [a_{12} + (a_i^2 + \alpha_i^2 \psi') a_{12}'] X_2'$,  

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:

$$\text{Max} Z = U(X_1', X_2') - v(G) + \lambda [L - [a_{11} + (a_i^1 + \alpha_i^1 \psi') a_{11}'] X_1' - [a_{12} + (a_i^2 + \alpha_i^2 \psi') a_{12}'] X_2']$$

subject to $X_1', X_2', \lambda > 0$.

From equation (7) we get the following first-order conditions for the $i$th country:
\[
\frac{\partial Z}{\partial X'_i} = U_j - v'(G)\phi' a'_{s_1} - \lambda [a_i' + (a_j' + a_k'\psi')]a_{s_1}' = 0,
\]
(8)
\[
\frac{\partial Z}{\partial X''_2} = U_2 - v'(G)\phi' a'_{s_2} - \lambda [a_i' + (a_j' + a_k'\psi')]a_{s_2}' = 0,
\]
(9)
\[
\frac{\partial Z}{\partial \lambda} = L - [a_i' + (a_j' + a_k'\psi')]a_{s_1}' X'_i - [a_i' + (a_j' + a_k'\psi')]a_{s_2}' X''_2 = 0.
\]
(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 \(X_j\) and \(X_k\) for the \(i\)th country. Let the optimum consumption levels be \(X'_i\) and \(X''_i\), respectively. Substituting these values of \(X'_i\) and \(X''_i\) into equation (2), we get the optimum production of the polluting good in the \(i\)th country as \(X'''_i\). Thus the optimum pollution caused by the \(i\)th country is \(\phi' X''_i\). Hence the optimum global pollution level becomes:
\[
\bar{R} = \phi^N X''^N + \phi^S X''^S.
\]
(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 \(\bar{R}\) 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 $\theta$ of technology transfer from the North to the South it holds that:

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

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 $\psi^S$ fraction of CO2 emitted per unit of $X_3$ production using $a^S_{41}$ units of labour. After receiving a better technology from the North it can abate an amount of $\theta \psi^N$ of CO2 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:

$$L = [a^S_{11} + (a^S_{11} + a^S_{43} \theta \psi^N) a^S_{41}] X^S_1 + [a^S_{21} + (a^S_{21} + a^S_{43} \theta \psi^N) a^S_{42}] X^S_2 \quad (13)$$

Writing $[a^S_{11} + (a^S_{11} + a^S_{43} \theta \psi^N) a^S_{41}]$ as $\alpha^S$ and $[a^S_{21} + (a^S_{21} + a^S_{43} \theta \psi^N) a^S_{42}]$ as $\beta^S$ we can rewrite equation (13) as:

$$L = \alpha^S X^S_1 + \beta^S X^S_2 \quad (14)$$

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

$$\frac{a^S_{31}}{a^S_{11} + (a^S_{11} + a^S_{43} \theta \psi^N) a^S_{41}} > \frac{a^S_{32}}{a^S_{21} + (a^S_{21} + a^S_{43} \theta \psi^N) a^S_{42}}$$

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

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 $X^N_1, X^N_2$ and $\theta$. In the second stage, the
South observes $X_1^N, X_2^N$ and $\theta$ and chooses its consumption levels $X_1^S$ and $X_2^S$ such that the global pollution level $G \leq \bar{R}$.

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 $\theta$ and later on incorporates the reaction functions to solve for the optimum values of $X_1, X_2$ and $\theta$. 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 CO2 per unit of $X_3$ production. So the emission of the South becomes $(1 - \theta\psi^N)$. Thus the value of $G$ now becomes:

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

(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:

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

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 $\theta$ are already determined in stage one. So the South takes $X_1^N, X_2^N$ and $\theta$ as given, while solving the problem. Now from equation (14) we can write:

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

(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:
Max $U = U(X^S_1, \frac{L - \alpha^S X^S_1}{\beta^S}) -
\nu[\phi^N(a^N_{31}X^N_1 + a^N_{32}X^N_2) + (1 - \theta \psi^N)(a^S_{31}X^S_1 + a^S_{32}\frac{L - \alpha^S X^S_1}{\beta^S})]. \tag{18}$

From equation (18) we get the following first-order condition for $X^S_1 > 0$:

$$U_1 - U_2 \frac{\alpha^S}{\beta^S} - \nu'(1 - \theta \psi^N)\alpha^S \left(\frac{a^S_{31}}{\alpha^S} - \frac{a^S_{32}}{\beta^S}\right) = 0 \tag{19}$$

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

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

Since $U_{11}, U_{22} < 0$ and $\nu'' > 0$, 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 $G < R$, then $\frac{dX^S_1}{dX^N_1} < 0$, $\frac{dX^S_1}{dX^N_2} < 0$ and $\frac{dX^S_1}{d\theta} > 0$.

**Proof:** Totally differentiating equation (19) and substituting $dX^N_2 = d\theta = 0$ we obtain:

$$\left[U_{11} + U_{22} \left(\frac{\alpha^S}{\beta^S}\right)^2 - \nu''(1 - \theta \psi^N)^2 \alpha^S \left(\frac{a^S_{31}}{\alpha^S} - \frac{a^S_{32}}{\beta^S}\right)^2\right] dX^S_1 =
\left[a^N_{31} \phi^N \nu^* (1 - \theta \psi^N) \alpha^S \left(\frac{a^S_{31}}{\alpha^S} - \frac{a^S_{32}}{\beta^S}\right)\right] dX^N_1.$$ 

Thus, we get:
\[ \frac{dX_1^S}{dX_1^N} = \left[ \frac{a_{31}^N \phi^N v^*(1 - \theta \psi^N) \alpha^S \left( \frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)}{U_{11} + U_{22} \left( \frac{\alpha^S}{\beta^S} \right)^2 - v^*(1 - \theta \psi^N)^2 \alpha^S \left( \frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right)^2} \right]. \]  

(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:

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

(22)

Rearranging terms yields:

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

(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:

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

\[ \alpha^S \left( \frac{a_{31}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S} \right) U_{22} a_2^N \psi^N \left( \frac{\alpha^S}{\beta^S} \right)^2 - \left[ v^*(1 - \theta \psi^N)^2 a_{32}^S a_4^N \psi^N \frac{\alpha^S}{\beta^S} - \psi^N v' - (1 - \theta \psi^N) v^N \psi^N X_3^N \right] d\theta. \]  

(24)

So we get:
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 $R$.

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:

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

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

$$L = \alpha^N X_1^N + \beta^N X_2^N.$$  

Rearranging of equation (27) yields:

$$X_2^N = \frac{L - \alpha^N X_1^N}{\beta^N}.$$  

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:

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

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

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

$$\theta \geq \frac{\psi^S}{\psi^N},$$  

$$\theta \leq 1.$$  

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

$$Z = U(X_1^N, \frac{L - \alpha^N X_1^N}{\beta^N}) - v[\phi^N(a_{31}^N X_1^N + a_{32}^N X_2^N) + (1 - \theta \psi^N)a_{31}^S X_1^S + a_{32}^S \frac{L - \alpha^S X_1^S}{\beta^S}].$$
\begin{align*}
+ \lambda_1 [\bar{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})\}] + \lambda_2 [1 - \theta] \\
+ \lambda_3 [\psi^S - \psi^N + \theta].
\end{align*}

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

\begin{align*}
\frac{\partial Z}{\partial X_1^N} &= U_1 - U_2 \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( a_{31}^S - a_{32}^S \frac{\beta^S}{\alpha^S} \right) \frac{\partial X_1^S}{\partial X_1^N} \right] = 0 \\
\frac{\partial Z}{\partial \theta} &= -(v' + \lambda_1) \left[ -\psi^N X_3^S + (1 - \theta \psi^N) \alpha^S \left( a_{31}^S - a_{32}^S \frac{\beta^S}{\alpha^S} \right) \frac{\partial X_3^S}{\partial \theta} \right] - \lambda_2 + \lambda_3 = 0 \\
\frac{\partial Z}{\partial \lambda_1} &= \bar{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 \\
\frac{\partial Z}{\partial \lambda_2} &= 1 - \theta \leq 0 \quad \text{and } \lambda_2 \frac{\partial Z}{\partial \lambda_2} = 0 \\
\frac{\partial Z}{\partial \lambda_3} &= -\psi^S \psi^N + \theta \leq 0 \quad \text{and } \lambda_3 \frac{\partial Z}{\partial \lambda_3} = 0
\end{align*}

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 $\bar{R}$, then (i) it offers a partial technology transfer, i.e. $\frac{\psi^S}{\psi^N} < \theta < 1$ when $G < \bar{R}$ and the extent of technology transfer is
\[ \theta^* = \frac{1}{\psi^S} \frac{\alpha^S X^S_1}{X^S_1} \varepsilon_1 \left( \frac{a^S_{31} - a^S_{12}}{\alpha^S + \beta^S} \right), \]  

(ii) it always offers complete technology transfer i.e.

\[ \theta = 1 \text{ when } G = \overline{R} \text{ and if } G < \overline{R} \text{ then complete technology is transferred when} \]

\[ \varepsilon_1 < \frac{\varphi \psi^N}{1 - \varphi \psi^N} \frac{X^S_1}{\alpha^S X^S_1} \left( \frac{a^S_{31} - a^S_{12}}{\alpha^S + \beta^S} \right) \]

and (iii) it does not transfer any technology i.e.

\[ \theta = \frac{\psi^S}{\psi^N}, \text{ if } G < \overline{R} \text{ and } \varepsilon_1 > \frac{\varphi \psi^N}{1 - \varphi \psi^N} \frac{X^S_1}{\alpha^S X^S_1} \left( \frac{a^S_{31} - a^S_{12}}{\alpha^S + \beta^S} \right). \]

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 \( \frac{v'}{U^S} \geq \frac{a^S_4}{\beta^S} \) 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

\[ \varepsilon_1 > \frac{\varphi \psi^N}{1 - \varphi \psi^N} \frac{X^S_1}{\alpha^S X^S_1} \left( \frac{a^S_{31} - a^S_{12}}{\alpha^S + \beta^S} \right). \]

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 $\bar{R}$ closes. So the North cannot increase its
production and enjoy higher welfare now as the pollution level can cross $\bar{R}$. So in this
situation it will take the decision of not transferring any abatement technology to the
South. Again, if $\epsilon_1 < \frac{\theta \psi^N}{1 - \theta \psi^N} \frac{X_1^S}{\alpha^S} \left( \frac{1}{\alpha^N - \frac{a_{31}^S}{a_{32}^S}} \right)$, then North will offer complete
technology transfer to the South if $G < \bar{R}$. This is because here if North makes any
technology transfer by marginal amount, then the output in the South will not change (if
$G = \bar{R}$) or it will increase by a much smaller amount when $G < \bar{R}$. 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 $\bar{R}$
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 $G = \bar{R}$, 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
$G < \bar{R}$, 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 \( \frac{V'}{U_2} < \frac{a_s^S}{\beta^S} \), 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 \( \frac{a_s^S}{\beta^S} \).

**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:

\[
\frac{a_i^N + (a_i^N + a_i^N \psi^N)a_i^N}{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S} > \frac{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S}{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S}
\]

(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:

\[
\frac{a_i^N + (a_i^N + a_i^N \psi^N)a_i^N}{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S} > \frac{p_1}{p_2} \frac{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S}{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S}
\]

(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:

\[
\frac{a_i^N + (a_i^N + a_i^N \psi^N)a_i^N}{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S} > \frac{1}{p} \frac{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S}{a_i^S + (a_i^S + a_i^S \psi^S)a_i^S}
\]

(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 \( X_1 \).

---

\(^4\) 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:

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

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

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

Let \( \tilde{X}_i^i \) and \( \tilde{X}_2^i \) denote the consumption of \( X_i \) and \( X_2 \) respectively after trade in the \( i \)th country, \( \forall \ i = N, S \).

So the budget constraint for the North becomes:

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

Similarly the budget constraint of the South is written as:

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

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

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

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

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

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

\[
R = \phi^N a_{32}^N X_2^N + \phi^S a_{31}^S X_1^S
\] (55)

The equation (55) leads to Lemma 2.

**Lemma 2:** \( R > \bar{R} \)

**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 $R$. So let $\theta$ be the extent of abatement technology that the North can transfer to the South. Here also the choice of $\theta$ is subject to the constraint as given in equation (12).

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

$$R = \phi^N a^N_{32} X^N_2 + (1 - \theta \psi^N) a^S_{31} X^S_1$$

$$= \phi^N a^N_{32} [\bar{X}^N_2 (p) + \bar{X}^S_2 (p)] + (1 - \theta \psi^N) a^S_{31} [\bar{X}^N_1 (p) + \bar{X}^S_1 (p)]$$

(56)

From equation (53) we get the following lemma:

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

**Proof:** Now differentiating both sides of equation (53) with respect to $\theta$ we get:

$$\frac{d\bar{X}^S_1}{dp} \frac{dp}{d\theta} + \frac{d\bar{X}^N_1}{dp} \frac{dp}{d\theta} = -\frac{a^S_4 \psi^N a^S_5 L}{[a^S_1 + (a^S_3 + a^S_4 \psi^S) a^S_{31}]^2}$$

That is

$$\frac{dp}{d\theta} = -\frac{a^S_4 \psi^N a^S_5 L}{[a^S_1 + (a^S_3 + a^S_4 \psi^S) a^S_{31}]^2} \frac{1}{\frac{d\bar{X}^S_1}{dp} + \frac{d\bar{X}^N_1}{dp}}$$

(57)

Note that in equation (57) the term \(\frac{d\bar{X}^S_1}{dp} + \frac{d\bar{X}^N_1}{dp}\) is negative by the Walrasian stability condition of the international equilibrium. Thus $\frac{dp}{d\theta} > 0$.

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:

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

From equation (51) we can write \( \tilde{X}_2^N = \left( p \frac{L}{[a_2^N + (a_3^N + a_4^N \psi^N)a_{12}^N]} - \tilde{X}_1^N \right) \frac{1}{p} \) and substituting it into equation (58) we have:

\[
U = U \left[ \tilde{X}_1^N \left( p \frac{L}{[a_2^N + (a_3^N + a_4^N \psi^N)a_{12}^N]} - \tilde{X}_1^N \right) \frac{1}{p} \right] - v(R) \tag{59}
\]

Maximising equation (59) with respect to \( \tilde{X}_1^N \) and \( \theta \) 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:

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

Using Lemma 3, we get \( \frac{\partial U}{\partial \theta} > 0 \), 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:

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

Modifying equation (52) after incorporating the technological parameter \( \theta \) we get:
\[ \tilde{X}_i^S + p\tilde{X}_i^S = \frac{L}{[a_i^S + (a_2^S + a_3^S \theta \psi^N) a_{31}^S]} \]  

Now South will maximise its welfare function as given in equation (62) using equation (63) as the constraint. From equation (63) we can write

\[ \tilde{X}_i^S = \frac{L}{[a_i^S + (a_2^S + a_3^S \theta \psi^N) a_{31}^S]} - p\tilde{X}_2^S \]  

and substituting it into equation (62) we have:

\[ U = U \left( \frac{L}{[a_i^S + (a_2^S + a_3^S \theta \psi^N) a_{31}^S]} - p\tilde{X}_2^S, \tilde{X}_2^S \right) - \nu(R) \]  

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

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

\[ \frac{\partial U}{\partial \theta} = \frac{dp}{d\theta} \left[ \frac{d\tilde{X}_2^S}{dp} (U_1(-p) + U_2) - U_1\tilde{X}_2^S \right] - \frac{La_2^S \psi^N a_{31}^S U_1}{[a_i^S + (a_2^S + a_3^S \theta \psi^N) a_{31}^S]^2} \]  

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

\[ \frac{\partial U}{\partial \theta} = \frac{dp}{d\theta} \left[ -U_1\tilde{X}_2^S \right] - \frac{La_2^S \psi^N a_{31}^S U_1}{[a_i^S + (a_2^S + a_3^S \theta \psi^N) a_{31}^S]^2} \]

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 $G < R$ 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:

$$
\left[(1 - \theta \psi^N) \alpha^S \left(\frac{a_{11}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right) \frac{\partial X_1^S}{\partial \theta}\right] = \psi^N X_3^S
$$

(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:

$$
\left[(1 - \theta \psi^N) \frac{\alpha^S X_1^S}{X_3^S} \left(\frac{a_{11}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right) \varepsilon_1\right] = \psi^N
$$

(40)

From equation (40) we get $\theta^* = \frac{1}{\psi^N} \frac{\alpha^S X_1^S}{X_3^S} \varepsilon_1 \left(\frac{a_{11}^S}{\alpha^S} - \frac{a_{32}^S}{\beta^S}\right)$.

Case II: Now suppose $\lambda_1 > 0$ and $\lambda_2 = \lambda_3 = 0$. This means that $G = R$ 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:

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

(41)
Note that from Lemma 1 we already have $\frac{\partial X_1^S}{\partial \theta} = 0$ when $G = \bar{R}$. 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 $\theta = 1$. Yet, we have partial technology transfer by assumption. Hence this case is inconsistent.

**Case III:** Let us assume that $\lambda_1 = \lambda_2 = 0$ and $\lambda_3 > 0$. This means at equilibrium $G < \bar{R}$ 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 $\bar{R}$. 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

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

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 $\lambda_1 > 0$, $\lambda_2 = $ and $\lambda_3 > 0$. Therefore, at equilibrium $G = \bar{R}$ 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):

$$
\frac{\partial Z}{\partial \theta} = (v' + \lambda_i) \psi^N X_1^S + \lambda_3.
$$

Using Lemma 1 we have $\frac{\partial X_1^S}{\partial \theta} = 0$, when $G = \bar{R}$. Here we also observe that $\frac{\partial Z}{\partial \theta} > 0$. In this situation the North will always choose complete technology transfer, that is $\theta = 1$. 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 $G < \bar{R}$ 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 $\frac{\partial Z}{\partial \psi} = 0$ we get:

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

or

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

or

$$\mathcal{E}_1 < \frac{\theta \psi^N}{1 - \theta \psi^N} \frac{X_3^s}{\alpha^s X_1^s} \left(\frac{a_{31}^s}{\alpha^s} - \frac{a_{32}^s}{\beta^s}\right).$$

**Case VI:** Let us suppose that $\lambda_1 > 0$, $\lambda_2 > 0$ and $\lambda_3 = 0$. So at equilibrium we have $G = \bar{R}$ 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:

$$(\nu' + \lambda_1)\psi^N X_3^s - \lambda_2 = 0 \quad (42)$$

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:

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

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

Differentiating equation (43) with respect to $\theta$ we find:

$$\frac{dU}{d\theta} = \frac{dX_1^s}{d\theta} \left[U_1 - U_2 \alpha^s \frac{a_{31}^s}{\alpha^s} - \nu'(1 - \theta \psi^N) \alpha^s \left(\frac{a_{31}^s}{\alpha^s} - \frac{a_{32}^s}{\beta^s}\right)\right] - U_2 \left[a_{31}^s \psi^N \left(\frac{a_{31}^s X_1^s}{\beta^s} + a_{32}^s X_2^s\right)\right]$$
By using the first-order condition of the South given in equation (19) as well as equation (2), we can write equation (44) as:

\[
\frac{dU}{d\theta} = -U_2 a_4^s \psi X_3^s + v' \psi^N X_3^s
\]

\[
= \psi^N X_3^s U_2 \left( \frac{v'}{U_2} - \frac{a_4^s}{\beta} \right)
\]

(45)

If \( G < \bar{R} \), then \( \frac{dU}{d\theta} \geq 0 \), if and only if \( \frac{v'}{U_2} \geq \frac{a_4^s}{\beta} \). Yet, if \( G = \bar{R} \), then \( v' = 0 \) which implies \( \frac{dU}{d\theta} < 0 \).
References


NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:
http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm
http://www.repec.org
http://agecon.lib.umn.edu
http://www.bepress.com/feem/

NOTE DI LAVORO PUBLISHED IN 2008

CCMP 1.2008 Valentina Bosetti, Carlo Carraro and Emanuele Massetti: Banking Permits: Economic Efficiency and Distributional Effects


KTHC 3.2008 Lorenzo Casaburi, Valeria Gattai and G. Alfredo Minerva: Firms’ International Status and Heterogeneity in Performance: Evidence From Italy

KTHC 4.2008 Fabio Sabatini: Does Social Capital Mitigate Precariousness?

SIEV 5.2008 Wisdom Akpalu: On the Economics of Rational Self-Medication

CCMP 6.2008 Carlo Carraro and Alessandra Sgobbi: Climate Change Impacts and Adaptation Strategies In Italy: An Economic Assessment


IEM 8.2008 Cristina Cattaneo, Matteo Manera and Elisa Scarpa: Industrial Coal Demand in China: A Provincial Analysis


CCMP 10.2008 Bob van der Zwaan and Reyer Gerlagh: The Economics of Geological CO2 Storage and Leakage

KTHC 11.2008 Maria Francesca Cracolici and Teodora Erika Uberti: Geographical Distribution of Crime in Italian Provinces: A Spatial Econometric Analysis


NRM 13.2008 Carlo Giupponi, Jaroslav Mysiak and Alessandra Sgobbi: Participatory Modelling and Decision Support for Natural Resources Management in Climate Change Research

NRM 14.2008 Vaella Depeiti and Carlo Giupponi: Science-Policy Communication for Improved Water Resources Management: Contributions of the Nostrum-DSS Project


CCMP 18.2008 Benno Torgler, María A.Garcia Valiñas and Alison Macintyre: Differences in Preferences Towards the Environment: The Impact of a Gender, Age and Parental Effect


CTN 20.2008 Pedro Pintassilgo, Michael Finus, Marko Lindroos and Gordon Munro (Ixxxiv): Stability and Success of Regional Fisheries Management Organizations


CTN 22.2008 Markus Kin atmosphere (Ixxxiv): Repeated Games Played in a Network


CTN 25.2008 Vasileios Zikos (Ixxxiv): R&D Collaboration Networks in Mixed Oligopoly

CTN 26.2008 Hans-Peter Weikard and Rob Dellink (Ixxxiv): Sticks and Carrots for the Design of International Climate Agreements with Renegotiations

CTN 27.2008 Jingang Zhao (Ixxxiv): The Maximal Payoff and Coalition Formation in Coalitional Games


CTN 30.2008 Rahmi Ilkiç (Ixxxiv): Network of Commons


CTN 32.2008 Billand Pascal, Frachisse David and Massard Nadine (Ixxxiv): The Sixth Framework Program as an Affiliation Network: Representation and Analysis

CTN 33.2008 Michele Breton, Lucia Shraga and Georges Zaccour (Ixxxiv): Dynamic Models for International Environmental Agreements
Carminel Guerriero: The Political Economy of Incentive Regulation: Theory and Evidence from US States

Irene Valsecchi: Learning from Experts

P. A. Ferrari and S. Salini: Measuring Service Quality: The Opinion of Europeans about Utilities

Michele Moretto and Gianpaolo Rossi: Vertical Integration and Operational Flexibility

William K. Jiaeger and Van Kolpin: The Environmental Kuznets Curve from Multiple Perspectives

Benno Torgler and Bin Dong: Corruption and Political Interest: Empirical Evidence at the Micro Level

Laura Onofri, Paolo A.L.D. Nunes, Jusone Cenoz and Dark Gorter: Language Diversity in Urban Landscapes: An econometric study

Gideon Krauseman and Lorenzo Pellegrini: Institutions and Forest Management: A Case Study from Swat, Pakistan

Pietro Caratti and Ludovico Ferraguto: Analysing Regional Sustainability Through a Systemic Approach: The Lombardy Case Study

Barbara Del Corpo, Ugo Gasparino, Elena Bellini and William Malizia: Effects of Tourism Upon the Economy of Small and Medium-Sized European Cities. Cultural Tourists and “The Others”

Dinko Dimitrov and Emiliya Lazarova: Coalitional Matchings

Joan Canton, Maia David and Bernard Sinclair-Desgagné: Environmental Regulation and Horizontal Mergers in the Eco-industry

Stephane Hallegatte: A Proposal for a New Prescriptive Discounting Scheme: The Intergenerational Discount Rate

Angelo Antoci, Paolo Russo and Elisa Tici: Structural Change, Environment and Well-being: Interactions Between Production and Consumption Choices of the Rich and the Poor in Developing Countries

Gian Luigi Albano, Federico Dini Roberto Zampino and Marta Fana: The Determinants of Suppliers’ Performance in E-Procurement: Evidence from the Italian Government’s E-Procurement Platform

Inmaculada Martínez-Zarzoso: The Impact of Urbanization on CO2 Emissions: Evidence from Developing Countries

Michele Moretto and Sergio Vergalli: Managing Migration through Quotas: an Option-theory Perspective

Ugo Gasparino, Elena Bellini, Barbara Del Corpo and William Malizia: Measuring the Impact of Tourism Upon Urban Economies: A Review of Literature

Reyer Gerlagh, Snorre Kverndokk and Knut Einar Rosendahl: Linking Environmental and Innovation Policy

Oguzhan C. Dincer and Burak Gunalp: Corruption, Income Inequality, and Poverty in the United States


Tannoyee Banerjee (Chatterjee) and Nilanjan Mitra: Export, Assembly-line FDI or FDI with the Possibility of Technology Diffusion: Optimal Entry Mode for Multinationals

Xavier Pautrel: Environmental Policy, Education and Growth: A Reappraisal when Lifetime Is Finite


Benno Torgler, Maria A. García-Valiñas and Alison Macintyre: Justifiability of Littering: An Empirical Investigation

Paolo Rosato, Anna Alberini, Valentina Zanatta and Margareth Breil: Redeveloping Derelict and Underused Historic City Areas: Evidence from a Survey of Real Estate Developers

Riccardo Nieva: Networks with Group Counterproposals

Michael Finus and Dirk T.G. Rübbelke: Coalition Formation and the Ancillary Benefits of Climate Policy

Elisabetta Strazzera, Elisabetta Cerchi and Silvia Ferrini: A Choice Modelling Approach for Assessment of Use and Quasi-Option Values in Urban Planning for Areas of Environmental Interest

Paolo Rosato, Lucia Rotaris, Margareth Breil and Valentina Zanatta: Do We Care about Built Cultural Heritage? The Empirical Evidence Based on the Veneto House Market

Luca Petrazzellis and Antonia Rosa Guerrieri: Does Network Matter in International Expansion? Evidence from Italian SMEs

Sheila M. Olnstad and Robert N. Stavins: Comparing Price and Non-price Approaches to Urban Water Conservation

Robert N. Stavins: Addressing Climate Change with a Comprehensive U.S. Cap-and-Trade System

Geoffrey J. Blanford, Richard G. Richels and Thomas F. Rutherford: Impact of Revised CO2 Growth Projections for China on Global Stabilization Goals

Valentina Bosetti, Carlo Carraro, Alessandra Sgobbi and Massimo Tavoni: Delayed Action and Uncertain Targets. How Much Will Climate Policy Cost?

Valentina Bosetti, Carlo Carraro and Massimo Tavoni: Delayed Participation of Developing Countries to Climate Agreements: Should Action in the EU and US be Postponed?

Massimiliano Mazzanti, Anna Montini and Francesco Nicolli: Embedding Landfill Diversion in Economic, Geographical and Policy Settings Panel based evidence from Italy

Reyer Gerlagh and Matti Liski: Strategic Resource Dependence

Sonia Ben Kheder and Natalia Zograva: The Pollution Haven Hypothesis: A Geographic Economy Model in a Comparative Study

Jérôme Massiani and Paolo Rosato: The Preferences of Trieste Inhabitants for the Re-use of the Old Port: A Conjoint Choice Experiment

Martin F. Quaas and Sjak Smulders: Pollution and the Efficiency of Urban Growth

Anil Markandya and Dirk T.G. Rübbelke: Impure Public Technologies and Environmental Policy
(lxxxiv) This paper was presented at the 13th Coalition Theory Network Workshop organised by the Fondazione Eni Enrico Mattei (FEEM), held in Venice, Italy on 24-25 January 2008.