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Technology Transfers and the Clean Development Mechanism in a North-South General Equilibrium Model

Summary

This paper analyzes the potential welfare gains of introducing a technology transfer from Annex I to non-Annex I in order to mitigate greenhouse gas emissions. Our analysis is based on a numerical general equilibrium model for a world economy comprising two regions, North (Annex I) and South (non-Annex I). As our model allows for labor mobility between the formal and informal sectors in the South, we are also able to capture additional aspects of how the transfer influences the Southern economy. In a cooperative equilibrium, a technology transfer from the North to the South is clearly desirable from the perspective of a 'global social planner', since the welfare gain for the South outweighs the welfare loss for the North. However, if the regions do not cooperate, then the incentives to introduce the technology transfer appear to be relatively weak from the perspective of the North; at least if we allow for Southern abatement in the pre-transfer Nash equilibrium. Finally, by adding the emission reductions associated with the Kyoto agreement to an otherwise uncontrolled market economy, the technology transfer leads to higher welfare in both regions.

Keywords: Climate Policy, Technology Transfer, Kyoto Protocol, General Equilibrium, Clean Development Mechanism

JEL Classification: D58, D62, Q52

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1. Introduction

The importance of international cooperation in order to address the climate problem is widely recognized. This is often exemplified by the Kyoto Conference of 1997, which resulted in a protocol with legally binding emission targets. The protocol sets binding targets for the industrialized countries (Annex I), while there are no such commitments for the developing countries (non-Annex I). A relevant question is how the climate policy can be implemented in a cost-efficient way in a world where only part of the countries faces explicit emission targets. The importance of cost-efficient implementation has been recognized by the UN Framework Convention on Climate Change (UNFCCC), Art. 3.3., which states that the climate policy should “ensure global benefits at the lowest possible cost”. In practice, this means that, although the emission targets are imposed on a limited number of countries, there is some flexibility in the implementation of these targets which allows for a more cost-efficient outcome than would otherwise be accomplished. One way of increasing the cost-efficiency is to introduce technology transfers from Annex I to non-Annex I.¹ In addition, a technology transfer needs not (necessarily) only be a means of lowering the abatement cost; it may also contribute to economic growth in the host country. However, despite that the idea of technology transfers has received attention in the (academic as well as policy) discussion, it has so far only played a minor role in practice.² In the light of these observations, the purpose of this paper is to examine the welfare effects of technology transfers in terms of a numerical general equilibrium model. Our approach will be explained more thoroughly below.

In the Kyoto protocol, the idea of technology transfers is formalized via the ‘Clean Development Mechanism’ (CDM), allowing Annex I countries to invest in projects aimed at reducing the emissions in non-Annex I countries and, at the same time, relax their own emission targets in exchange for the emission reduction induced by these projects. The purpose of the CDM is “to assist parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the convention and to assist Annex I countries in reaching their targets”.³ Earlier studies typically model the CDM in a way similar to emission trading.⁴ However, this approach fails to recognize the first part of the

¹ See e.g. Forsyth (1999) and Grubb (2000).

² See e.g. Forsyth (1999).

³ See Article 12 in the Kyoto Protocol.

⁴ See e.g. Ellerman, Jacoby and Decaux (1998) and Zhang (2001).

purpose of the CDM (to assist non-Annex I in achieving sustainable development). Another aspect of relevance for our analysis is that the ‘non-carbon welfare effects’ associated with the CDM are potentially very important for the non-Annex I countries, when they decide on whether or not to participate in projects aiming at lower emissions. In case studies focusing on Brazil, China and India, it is shown that these countries could benefit substantially from many viable abatement projects. The non-carbon benefits include, for instance, improved air and water quality, electrification of rural and remote areas, and increased employment.⁵

In this paper, we simulate the welfare effects of introducing a technology transfer in a stylized world-economy comprising two regions; the North (Annex I) and the South (non-Annex I). Our analysis is based on a numerical general equilibrium, in which agents make intertemporal choices. The data and parameters for the regions are, to a large extent, based on the RICE- and DICE-models.⁶ Clearly, the welfare effects of a technology transfer depend on the pre-transfer resource allocation. We consider three different regimes; (i) the regions behave as uncontrolled (or imperfectly controlled) market economies – a regime which is also extended by allowing for the requirement of emission reductions in the North due to the Kyoto protocol, (ii) the pre-transfer resource allocation is a noncooperative Nash equilibrium, and (iii) the pre-transfer resource allocation is a conditional cooperative equilibrium, where ‘conditional’ means that the resource allocation is decided upon in the absence of the option of using the transfer. The first two regimes are interesting in the sense of representing two extreme views on how the regions behave in the absence of cooperation. The uncontrolled market economy means that all externalities generated by each region remain uninternalized at the equilibrium, whereas the noncooperative Nash equilibrium implies that each region internalizes the externalities it imposes on the domestic residents (while the transboundary externalities remain uninternalized). Although the noncooperative Nash equilibrium appears to be the most common alternative to cooperation in earlier literature on international environmental policy, both these regimes have been addressed before in various contexts.⁷ Despite being unrealistic from a (current) practical policy perspective, the conditional cooperative equilibrium is interesting for purposes of comparison, as it allows the preferences

⁵ See e.g. Austin and Faeth (1999).

⁶ See Nordhaus and Yang (1996).

⁷ For a more detailed discussion, see also the theoretical literature dealing with transboundary environmental problems; e.g. Carraro and Siniscalco (1993), Barrett (1994), Tahvonen (1994), Aronsson and Blomquist (2003), Aronsson et al. (2004) and Aronsson et al. (2006).

of both the North and the South (and not just the North as in the other two regimes) to govern the decision underlying the use of the technology transfer.

In addition to the distinction between the three regimes mentioned above, another novelty is that we divide the Southern economy in a formal and an informal sector, which is reasonable since the informal sector seems to play a much more important role in developing economies than in developed economies⁸. This enables us to analyze the effects of labor mobility between the two sectors following a technology transfer. By assumption, the formal sector is more capital intensive than the informal sector and is characterized by higher average productivity. From the perspective of the North, the technology transfer is motivated by the difference in abatement costs between the regions. However, a technology transfer may also be thought of as an investment in a new and more efficient abatement technology, which might increase total factor productivity in the Southern formal sector. The issue of unilateral technology transfers from the North to the South was raised by Yang (1999). He considers the impact of such transfers in a dynamic general equilibrium model, where greenhouse gases give rise to a global externality. At the same time, the technology transfer in Yang's model does not have any direct effects on the Southern economy other than a reduction of greenhouse gas emissions; in other words, Yang did not address the productivity-oriented effect mentioned above. Another difference between Yang's model and ours is that we allow the abatement cost differential between the regions to depend on the abatement efforts chosen by the South. Therefore, the benefits of a technology transfer from the North to the South depend on the level of abatement implemented by the Southern economy prior to the implementation of the transfer.

The outline of the paper is as follows: In section 2, we present the basic structure of our numerical model. Section 3 describes the data as well as the ideas underlying the calibration. The results are presented in section 4. Section 5 gives the concluding remarks.

2. The Numerical Model

Consider a world economy comprising two regions, North (n) and South (s). The model to be described below is, to a large extent, based on the Rice-model developed by Nordhaus and

⁸ See e.g. Ihrig and Moe (2000).

Yang (1996) with the extensions mentioned in the previous section. The model is highly stylized and focuses on environmental interaction. To simplify the analysis, we follow earlier comparable literature by disregarding international factor mobility and trade (although we allow for labor mobility within the Southern economy, as mentioned above). This does not reflect a belief that international factor mobility and trade are unimportant; only that the underlying incentives are not easily captured by our model, which is designed to examine the effects of technology transfers from Annex I to non-Annex I.

We use the following notations (neglecting the region-specific indicator);

C	Aggregate consumption
N	Employment
K	Capital stock
$c=C/N$	Consumption per capita
I	Investments
E	CO ₂ emissions
σ	CO ₂ emissions per unit of output
μ	CO ₂ emission control rate (a measure of abatement)
Tr	Technology transfer
T_E	Atmospheric temperature

Let us begin by presenting the consumption part of the model. Each region is characterized by identical individuals⁹ and a variable population. The objective function underlying public policy in each region is assumed to be utilitarian

$$U_0^j = \sum_{t=0}^{\infty} N^j(t) u^j(c^j(t)) [1 + \theta]^{-t} \quad (1)$$

for $j = n, s$, where $u^j(\cdot)$ is the instantaneous utility function facing each resident and θ the utility discount rate. Each individual supplies one unit of labor inelastically at each point in time. By analogy to equation (1), the objective function underlying cooperative behavior is also utilitarian, i.e.

$$W_0 = U_0^n + U_0^s \quad (2)$$

⁹ This assumption simplifies the analysis considerably. In the context of the South, it means that the representative agent earns part of his/her income from the formal sector and part from the informal sector.

The instantaneous utility function takes the Cobb-Douglas form

$$u^j(c^j(t)) = [c^j(t)]^\rho \quad (3)$$

in which $\rho \in (0,1)$ is a fixed parameter and reflects the degree of concavity of the instantaneous utility function.

Turning to the production structure, we assume that both regions are characterized by Cobb-Douglas technologies. Despite this similarity, there are several differences between the regions. The production function for the North is written

$$Q^n(t) = \tilde{A}^n(t) \Omega^n(t) K^n(t)^{\gamma^n} N^n(t)^{1-\gamma^n} \quad (4)$$

where $\tilde{A}^n(t) = A^n(t)[1 + \zeta \mu^n(t)]$ represents the level of technology in period t , meaning that we allow for the possibility of ‘abatement driven’ technological change, and $A(t)$ is an exogenous time-dependent function. The expression $\Omega^n(t) = 1/[1 + \theta_1^n TE(t) + \theta_2^n TE(t)^2]$ represents the production externality due to global warming. We will return to the assumptions about the fixed parameters γ^n , ζ , θ_1^n and θ_2^n below. The output net of abatement and transfer expenditures, which can be used for domestic consumption and net investments, is given by

$$Y^n(t) = Q^n(t)[1 - \alpha_1^n(t) \mu^n(t)^{\alpha_2^n}] - \omega(Tr(t)) \quad (5)$$

in which $\omega(Tr(t))$ is the cost of the technology transfer, whereas $\alpha_1^n(t)$ and α_2^n characterize the abatement technology available in period t . The expression within the brackets reflects the cost of abatement in terms of lost output, whereas the final term (the cost of the technology transfer) is determined by the abatement technology available in the Southern region in period t and is, therefore, dependent on the Southern abatement cost. This is described more thoroughly below. Capital formation is governed by

$$K^n(t) = (1 - \delta)K^n(t-1) + I^n(t) \quad (6)$$

where $\delta \in (0,1)$ is the rate of capital depreciation.

In the South, there is a distinction between the formal (f) and informal (i) sectors. The production functions are written

$$Q_f^s(t) = \tilde{A}_f^s(t) \Omega^s(t) K_f^s(t)^{\gamma_f^s} N_f^s(t)^{1-\gamma_f^s} \quad (7)$$

$$Q_i^s(t) = A_i^s(t) \Omega^s(t) K_i^s(t)^{\gamma_i^s} N_i^s(t)^{1-\gamma_i^s} \quad (8)$$

Since the Southern economy comprises two sectors, we have $N_f^s = n_f^s N^s$ and $N_i^s = n_i^s N^s$, where n_f^s and n_i^s represent the share of the labor unit that each individual supplies to the formal and informal sector, respectively. The parameterization of equations (7) and (8) is analogous to that of equation (4). The technology function in equation (7), i.e.

$$\tilde{A}_f^s(t) = A_f^s(t) [1 + \zeta (\mu^s(t) + Tr(t))],$$

reflects the idea that the technological change in the formal sector is driven both by domestic abatement (as in the North) and the technology transfer, whereas $A_i^s(t)$ in equation (8) is an exogenous and time-dependent technology function in the informal sector. The fixed parameter $\zeta > 0$ will be determined below. By analogy to the production structure in the North, the production externality is defined as $\Omega^s(t) = 1/[1 + \theta_1^s TE(t) + \theta_2^s TE(t)^2]$. Finally, the part of output used for domestic private consumption and net investments is given by

$$Y^s(t) = Q^s(t) [1 - \alpha_1^s(t) \mu^s(t)^{\alpha_2^s}] \quad (9)$$

meaning that we allow for abatement efforts also in the South, although our reference case below is based on the assumption that the South does not abate. The capital formation in the two sectors is governed by

$$K_f^s(t) = (1 - \delta) K_f^s(t-1) + I_f^s(t) \quad (10)$$

$$K_i^s(t) = (1 - \delta) K_i^s(t-1) + I_i^s(t) \quad (11)$$

Let us now turn to the external effect. The total emissions of carbon dioxide are given by

$$E(t) = E^n(t) + E_f^s(t) + E_i^s(t) \quad (12)$$

where the three components on the right hand side (measuring emissions in the North, emissions in the formal sector in the South and emissions in the informal sector in the South, respectively) are defined as

$$E^n(t) = \sigma^n(t)[1 - \mu^n(t)]Q^n(t) \quad (13)$$

$$E_f^s(t) = \sigma_f^s(t)[1 - \mu^s(t) - Tr(t)]Q_f^s(t) \quad (14)$$

$$E_i^s(t) = \sigma_i^s(t)Q_i^s(t) \quad (15)$$

The flow of carbon dioxide emissions in equation (12) gives rise to stocks of greenhouse gases in the air and water which, in part, determine how the temperature influences the output. This relationship is described in the Appendix A.

3. Data Sources and Model Calibration

Our model is mainly based on the data and parameters from the RICE-99 and DICE-99 economic models of global warming.¹⁰ From the original RICE-99-model with 13 regions, Japan, the U.S., Europe, other high income countries, Russia and Eastern Europe are aggregated into region North. The North can also be called ‘Annex I’, because it contains all countries that are subject to emission targets in the Kyoto protocol.¹¹ China, India, Africa and other low- and middle income regions are aggregated into the Southern region and can also be seen as the developing countries, which have made no commitments to reduce their emissions. The base year in our model is 1990, and the time horizon is 20 periods, where each period represents one decade. However, following Nordhaus and Yang (1996), we have chosen to present the equilibrium paths of some of the key variables during a shorter time

¹⁰ See Versions 020899, available at <http://www.econ.yale.edu/~nordhaus/homepage/homepage.htm>.

¹¹ A list of the Annex I countries can be found in the Kyoto Protocol. Out of these 40 countries, only the U.S., Australia and Monaco had not yet ratified the Protocol on February 6, 2006.

period; more exactly, the first 13 periods (1990-2110). The welfare analysis for each of the three regimes is conducted by using all 20 periods.

The possible gains for the North, from carrying out the technology transfer, depend on the preexisting level of abatement in the South (i.e. the level chosen prior to the technology transfer). The more domestic abatement the South has already accomplished, the higher will be the cost of abatement. In other words, the South has the opportunity to choose its domestic level of abatement before the North decides upon the technology transfer. This approach differs from Yang (1999); he assumes that the North has access to a given technology, which can be used either for domestic abatement or as a technology transfer, while the cost of the transfer does not depend on the current level of abatement in the South. However, from the perspective of the CDM, it is also interesting to consider situations where the South chooses to abate before the technology transfer is carried out. The reason is that it should not (according to the Kyoto protocol) be possible for the North to capture ‘low-cost’ abatement opportunities in the South, if there is a chance that the abatement project would have been implemented without the CDM.

As we indicated above, another difference in comparison with earlier research is that the production in the South has been divided into a formal and an informal sector. It is a common feature that the informal sector is significantly larger in developing countries than in industrialized countries. Estimates of the informal sector share of GDP in the developing countries average more than one third, while the corresponding share in the OECD is much smaller.¹² This leads to more uncertain estimates of the actual GDP in the developing countries. We assume that there is an additional ‘hidden’ informal sector of about one third of the production in the formal (observed) sector in the Southern economy. The informal sector is more labor intensive than the formal sector, and the average productivity is lower than in the formal sector. This implies that a movement of labor from the informal to the formal sector will most likely lead to higher output in the Southern economy.

We calibrate the model in such a way, that the production in the Southern formal sector corresponds to the observed regional equivalent to GDP, and the industrial emissions of the South are equal to the observed emissions, at the beginning of the planning period. Note that

¹² See Ihrig and Moe (2000).

the observed industrial emissions originate from the formal sector; this assumes that there are no large industries in the informal sector. However, there is also another source of emissions, which is treated as exogenous in the original RICE-99 and DICE-99 models. This source refers to land-use emissions, which mainly originate from the harvesting of forests in the developing countries. At present, these constitute about 20 per cent of the total emissions from the developing countries.¹³ Realizing that a sector without large industries can be a significant source of emissions, we have chosen to transform the exogenous land-use emissions into endogenous emissions in the informal sector. In the reference case (see below), the informal sector emissions decrease over time in a way similar to the path for the exogenous land-use emissions in the original RICE-99 and DICE-99 models. The possibility to control emissions via investments in abatement technologies is assumed only to exist in the formal sector, which means that in order to change the path of the emissions in the informal sector, the size of the informal sector must be changed.

The difference in marginal abatement costs between the regions motivates the transfer from the North to the South. In addition, as we indicated above, there may be an extra gain for the South associated with the transfer. This is recognized by allowing the total factor productivity (TFP) of the regions to depend on the emission control rate. For the Southern economy, both the domestic abatement and the technology transfer affect the TFP. The productivity effect associated with the technology transfer gives rise to labor mobility from the informal to the formal sector in the South. This implies increased output and possibly also higher emissions in the Southern formal sector.

Our choices of parameter values are described in the Appendix B, and Section 4.4 contains a sensitivity analysis for some of these parameters (the parameters we have added by extending the original RICE-99 and DICE-99 models).

4. Simulation results

As mentioned in the introduction, we distinguish between three different resource allocations prior to the introduction of the transfer; (i) the resource allocation is a weakly controlled (or uncontrolled) market economy, which in some of the calculations is extended to reflect the

¹³ See IPCC (2001).

emission targets in the Kyoto protocol, (ii) the resource allocation is a cooperative equilibrium, and (iii) the resource allocation is a noncooperative Nash equilibrium in open-loop form. The comparison to be carried out refers to the present value of future consumption in each region as well as at the global level; entities which are observable (or estimable) in practice. Note also that the three regimes only differ with respect to the environmental policy; we do not explicitly address other aspects of public policy. This enables us to concentrate the comparison to environmental policy aspects, which is in line with earlier, comparable, research. Equilibrium paths for key variables are presented in the Appendix C. Our reference case, by which the other regimes is compared, is the uncontrolled market economy, in which there is no policies to reduce the emissions of greenhouse gases. In each of the pre-transfer resource allocations described above, we present results from a baseline simulation, where the option of using the technology transfer is not available. Other simulations are based on the assumption that the size of the technology transfer is subject to choice (by the global social planner in the cooperative regime and by the North in the noncooperative regimes). We also relate the incentives of using the transfer to whether or not the South is carrying out domestic abatement.

4.1 Imperfectly Controlled Market Economies

The uncontrolled market economy is a projection of what would happen if no government intervention were used to slow down the global warming. Emissions are treated as a side effect of the production, meaning that the welfare effects of these emissions are not incorporated into the decision-problems. In this case, the global temperature increase (relative to the exogenous base temperature) by the year 2110 is simulated to be 2.463 degrees Celsius¹⁴. The emission paths for each region¹⁴ can be seen in Appendix C (Figure 1). It is interesting to note that, within a few decades, the South will be the main emitter of carbon dioxide, while the simulated emission path for the North is relatively constant. However, in terms of emissions per capita, the South will not reach the level of the North during the whole simulation period.

Table 1: Results: Imperfectly Controlled Market Economies

Here

¹⁴ The measure of temperature, degrees Celsius, is the temperature increase in period 13 compared to a base temperature level.

In order to address how the emission reductions implicit in the Kyoto protocol affect the resource allocation and consumption possibilities, the Kyoto restriction is implemented as a scenario where the North faces an emission constraint of stabilizing the emissions to 5% under the 1990 year level by the year 2008-2012 (period 3 in the model). The South is assumed not to take any actions to reduce its emissions. In our analysis, the Kyoto restriction imposed on the North holds during the remaining planning period. Given the Kyoto restriction, the temperature increase is estimated to be about 2.410 degrees Celsius, whereas the temperature increase in the uncontrolled market economy (our reference case) is 2.463 degrees Celsius. This confirms the finding of other studies that the Kyoto protocol will have a modest effect on the mean temperature level. If the option of using the technology transfer is not available (the second line in the table), the present value of consumption for the North is smaller than in the reference case, although the present value of consumption is higher at the global level.¹⁵

Opening up the possibility of using the technology transfer, this option will be used by the North from the period the Kyoto restriction becomes binding. As a consequence, the present value of future consumption increases for both the North and South relative to the case when this option is not available. Interestingly, the present value of future consumption facing the North actually becomes larger than in the uncontrolled market economy. By comparing the second and third rows in the table, we can see that the possibility of using the technology transfer implies a gain for the North of about 540 billion U.S. \$.¹⁶ As such, this gives an indication of the potential gains for the North of using the technology transfer. The gains for the South are mainly explained by increased output accompanied by labor mobility from the informal to the formal sector. The total increase in present value of future consumption for the South, compared to the case in which no transfer is used, is 43 billion U.S. \$. This is partly due to the overall productivity gain (at constant employment shares) and partly to labor mobility. The additional gain associated with labor mobility is relatively small by comparison;

¹⁵ Recall that the North in our model comprises all Annex I countries; also the U.S., Australia and Monaco, which have not yet ratified the protocol.

¹⁶ Since the size of the transfer depends on the abatement already implemented by the South, it is interesting to note that even if the South were to choose the same rate of emission control as in the Nash equilibrium (see below), it would still be in the North's interest to use a positive technology transfer in order to reach the Kyoto target at minimum cost.

about 2-3 billion U.S. \$.¹⁷ The size of the technology transfer, given the emission reduction targets in the Kyoto protocol, is about 5 billion U.S. \$ in the first period and 2 billion in the last period of analysis. As such, it only represents a small part of the wealth of the North, which is shown in the Appendix C (Figure 2).

It is also interesting to compare the size of the transfer in our model during period 3 (which is the period when the Kyoto restriction becomes implemented) with the observed amount of resources spent on such climate projects in the developing countries during the time period 1991-1997. Clearly, the size of the transfer implied by our model exceeds the observed amount of resources spent during that time period.¹⁸ This may either imply that our model exaggerates the incentives to use the technology transfer, or that the Kyoto agreement creates incentives to increase the technology transfer.¹⁹

4.2 The Cooperative Equilibrium

The cooperative equilibrium concept adopted here is based on the assumption that a global social planner maximizes the sum of the region-specific objective function subject to all restrictions described in section 2. This means that the marginal costs and benefits of emission control balance at the global level. It is the latter aspect of cooperation that we would like to capture; we are not assuming that the regions pool all their resources into one single resource constraint.

Table 2: Results: Cooperative equilibrium

Here

In the baseline simulation, which does not allow for the technology transfer from the North to the South, the environmental policy is limited to the emission control rates for the two regions. Clearly, the present value of future consumption is higher in both regions than in the reference case (the uncontrolled market economy), and the temperature increase becomes 2.098 degrees Celsius.

¹⁷ Although this effect appears to be small, note that it implies a movement of the equivalent of about 1-10 million workers in each time period from the informal to the formal sector.

¹⁸ See Michaelowa (2000).

¹⁹ Transaction costs are often described as obstacles in the context of implementation of technology transfers. Our model does not include transaction costs.

Let us now turn to the second row of Table 2, where we introduce the option of using the technology transfer. Our results imply that this option will be used during the entire simulation period. This leads to an increase in the present value of future consumption at the global level. The optimal domestic emission control rates of the North and South do not change much in comparison with the baseline simulation. Therefore, by introducing the technology transfer, the emissions will be reduced. Note that the technology transfer makes the North worse off relative to the baseline simulation. However, the gain for the South outweighs the loss for the North; the implication in the table is that the present value of future consumption increases at the global level. Once again, the welfare gain of the technology transfer for the Southern economy is partly due increased productivity accompanied by labor mobility from the informal to the formal sector. However, the latter (productivity-related) effect only constitutes a small part of the total increase in the present value of future consumption for the Southern economy.

If we impose the restriction that the emission control rate of the South should be equal to zero (the third row in Table 2), then the optimal size of the technology transfer increases relative to the previous simulation, where the Southern emission control rate is chosen freely by the global social planner. The emission control rate for the North does not change significantly, and the considerable size of the technology transfer brings the Southern industrial emissions near the level associated with the previous simulation. This means that the global social planner uses the technology transfer as an imperfect substitute for Southern abatement; the option of which is no longer available. The North becomes worse off, even in comparison with the uncontrolled market economy, while the South becomes much better off. The effect of labor mobility becomes more important when the Southern abatement is set to zero and amounts to about 25 billion U.S. \$ in terms of its contribution to the present value of future consumption. The emission paths are shown in the Appendix C (Figure 3). Note that the emissions path of the North does not change significantly when the technology transfer is introduced; the most important effect is, instead, that the emissions of the South are reduced.

The share of the transfer in the regional equivalent to GDP for the North is shown in the Appendix C (Figure 4), where we concentrate on the scenario giving the highest present value

of future consumption (the second row in Table 2). The cost of the transfer ranges from 0.15 billion 1990 U.S. \$ in the first time period to 17 billion U.S. \$ in period 13, which is shown in the Appendix C (Figure 5). Our model implies a smaller technology transfer than found by Yang (1999)²⁰. Except that the North and South in our model do not include exactly the same countries as the corresponding regions in Yang's model, one reason for a smaller technology transfer in our case is that the cost of the transfer depends on the level of domestic abatement implemented in the South. The larger the Southern emission control rate, the smaller the marginal abatement cost differential between the regions. Notice that these numbers for the transfer are based on the simulation, where the emission control rate of the South is positive. If, on the other hand, the emission control rate of the Southern economy is not a decision variable for the global social planner, the results change dramatically. In the latter case, the size of the transfer ranges from 2 billion U.S. \$ in the first period up to 433 billion U.S. \$, which is considerably higher than in the corresponding estimates by Yang. Therefore, in our model, the assumptions about which abatement policy options are available in the South are of considerable importance for the optimal size of the technology transfer.

4.3 The Noncooperative Nash Equilibrium

The noncooperative Nash equilibrium concept is based on the assumption that the resource allocation in each region is decided upon by a domestic social planner, who treats the policies chosen by the other region as exogenous. As a consequence, since each regional planner only considers the welfare facing the domestic residents, the domestic welfare effects associated with greenhouse gases will become internalized, whereas the transboundary external effect remains uninternalized.

Table 3: Results: Noncooperative Nash Equilibrium

Here

Consider first the baseline simulation, where it is not possible to carry out the technology transfer. This means less emission control and a larger increase in the average temperature – 2.192 degrees Celsius – than in the cooperative equilibrium. However, note that the difference in present value of future consumption between the cooperative equilibrium and the

²⁰ The transfer in the corresponding scenario of Yang's model ranges from about 1 billion to 80 billion U.S. \$.

noncooperative Nash equilibrium is relatively small at the global level; the difference between, on the one hand, these two resource allocations and, on the other, the uncontrolled market economy is much greater. Therefore, if each region chooses its environmental policy in order to maximize its own welfare, while treating the actions of the other region as given, we may actually come relatively close to the global optimum.

Now, consider the effects of introducing the technology transfer. If the South chooses its emission control rate in an optimal way, it is not in North's interest to transfer technology to the South. Although the transfer increases the welfare at the global level, the North would become worse off. This is not surprising; the abatement carried out by the South reduces the abatement cost differential between the regions. If, on the other hand, the emission control rate of the South is restricted to be equal to zero prior to the introduction of the transfer, then the North will choose to make a transfer to the South; the abatement cost differential becomes much greater here than when the Southern emission control rate is subject to choice. However, the present value of future consumption becomes much smaller at the global level, indicating that Southern abatement is important from the perspective of global welfare. The industrial emissions in the cooperative equilibrium and the noncooperative Nash equilibrium are shown in the Appendix C (Figure 6).

4.4 Sensitivity Analysis

We have carried out sensitivity analyses for some of the parameters in the model. The sensitivity analyses refer to (i) the production functions in the South, (ii) the relationship between technological change and abatement, (iii) the ratio between emissions and output, and (iv) the production externality. We only discuss the qualitative results of these sensitivity analyses here. Details are available from the authors upon request.

In the simulations presented in the main text, the parameter attached to the capital stock in the production function for the Southern formal sector, γ_f^s , takes the same value as the corresponding parameter in the northern production function. These estimates originate from the RICE- and DICE-models. On the other hand, the parameter attached to the capital stock in the production function of the Southern informal sector, γ_i^s , is smaller, which is motivated by the assumption of more labor intensive production. The first sensitivity analysis suggests the

qualitative results are not sensitive to small changes in γ_f^s and γ_i^s ; the simulation results still imply a reallocation of labor from the informal to the formal sector in the South. Turning to the second sensitivity analysis, we find that the larger the productivity effect of abatement, i.e. the parameter ζ , the larger will be the reallocation of labor between sectors in the South. Therefore, an increase in the parameter ζ contributes to increase the effect of the technology transfer on the Southern economy. The third simulation eliminates part of the region-specific difference in the ratio between emissions and output. The qualitative results remain as they are in Tables 1-3.

As mentioned above, we have also carried out a sensitivity analysis for the parameters in the damage functions associated with temperature increase, i.e. the production externality. In Tables 1-3, the damage facing the regions due to a temperature increase of 2.5 degrees Celsius is assumed to be of the order of 1 per cent of GDP for the North and 2 per cent of GDP for the South. These assumptions correspond closely with the original RICE and DICE-models. Our sensitivity analysis means that these effects are doubled. Interesting to note here is that the emissions chosen by each region are reduced substantially in comparison with those associated with the original model; for the North, the emissions are reduced well below the levels following from the Kyoto Protocol restriction. In the Nash equilibrium version of the model, the most important qualitative result remains unchanged; the North will not use the technology transfer, as long as the South carries out abatement.

5. Conclusions

This paper deals with the consequences of introducing a technology transfer from the North to the South in the context of a numerical general equilibrium model. Our model comprises two regions, North and South, where the North represents the so called Annex I, or industrialized, countries in the Kyoto protocol, and the South represents the non-Annex I, or developing, countries. We distinguish between three different resource allocations prior to the introduction of the transfer; (i) the resource allocation is an otherwise uncontrolled market economy extended to reflect the emission targets in the Kyoto protocol, (ii) the resource allocation is a cooperative equilibrium, and (iii) the resource allocation is a noncooperative Nash equilibrium in open-loop form.

We find that a technology transfer from the North to the South, if designed appropriately, reduces the emissions and increases welfare at the global level. If the regions behave as Nash competitors prior to the introduction of the technology transfer, and although the transfer leads to higher welfare at the global level, the incentives of using this transfer appear to be weak from the perspective of the North. The reason is that the abatement carried out by the South in our model tends to reduce the abatement cost differential between the regions. On the other hand, if we were to add the restriction that the South does not abate its own emissions, our results suggest that the North will, indeed, make a technology transfer to the South. The intuition is that the abatement cost differential (prior to the introduction of the technology transfer) becomes relatively large in this case. Therefore, if the industrialized countries are concerned with climate change, and the developing countries are only taking trivial steps to reduce their own emissions, our results suggest that it is in the interest of the industrialized countries to transfer environmental technology to achieve abatement in a more cost-efficient way. From the Southern perspective, the technology transfer may imply large benefits; both in terms of a better environment and in terms of technological change followed by a reallocation of resources from the informal to the formal sector.

It is also interesting to analyze the role of the technology transfer in the context of a (hypothetical) cooperative equilibrium, as it implies that the transfer is governed by the preferences of the citizens in the North and the South. In this case, the (Utilitarian) global social planner would use the transfer instrument, because the welfare increase facing the residents in the South outweighs the welfare loss facing the residents in the North. The optimal policy implicit in the cooperative equilibrium implies abatement of the emissions originating from both regions and a technology transfer from the North to the South.

Given the Kyoto Protocol, part of the Annex I countries has agreed to reduce the industrial emissions, while there are no such commitments for the developing countries. What role does the CDM play in combination with the emission reductions in the Kyoto Protocol? In the context of the reference scenario of our model, where the regions were uncontrolled market economies prior to the agreement, we have incorporated the Kyoto Protocol restriction along with the possibility for the North of using the technology transfer. Our results imply that the North will make technology transfers to the South in this case. In addition, although the Kyoto Protocol would be beneficial for the South even without the technology transfer, the use of the transfer contributes to increase the welfare in the South, partly by a reallocation of resources

from the informal to the formal sector. The productivity effect following the transfer can be seen as new employment opportunities in the formal sector, which is one of the non-carbon benefits often mentioned in the discussion of CDM-projects. Therefore, given the assumptions of which our model is based, the technology transfer may contribute to cost-efficient abatement from the perspective of the North and economic development in the South; let be that the magnitude of the latter effect is subject to considerable uncertainty.

Appendix A

Additional notation

M_{AT}	Atmospheric CO ₂ concentrations
M_{UP}	concentrations in upper oceans
M_{LO}	concentrations in lower oceans
T_E	Atmospheric temperature change
T_{LO}	Oceanic temperature change
F	Total radiative forcing
O	Exogenous radiative forcing
Ω	Damage function

Following Nordhaus and Yang (1996), we have

$$M_{AT}(t) = E(t) + b_{11}M_{AT}(t-1) - b_{12}M_{AT}(t-1) + b_{21}M_{UP}(t-1) \quad (\text{A1})$$

$$M_{AT}(0) = M_{AT}^0$$

$$M_{UP}(t) = b_{22}M_{UP}(t-1) + b_{12}M_{AT}(t-1) - b_{21}M_{UP}(t-1) + b_{32}M_{LO}(t-1) - b_{23}M_{UP}(t-1) \quad (\text{A2})$$

$$M_{UP}(0) = M_{UP}^0$$

$$M_{LO}(t) = b_{33}M_{LO}(t-1) - b_{32}M_{LO}(t-1) + b_{23}M_{UP}(t-1) \quad (\text{A3})$$

$$M_{LO}(0) = M_{LO}^0$$

$$F(t) = \eta \left(\frac{\log(M_{AT}(t) / M_{AT}^0)}{\log(2)} \right) + O(t) \quad (\text{A4})$$

$$T_E(t) = T_E(t-1) + \beta_1[F(t) - \lambda T_E(t-1) - \beta_2(T_E(t-1) - T_{LO}(t-1))] \quad (\text{A5})$$

$$T_E(0) = T_E^0$$

$$T_{LO}(t) = T_{LO}(t-1) + \beta_3[T_E(t-1) - T_{LO}(t-1)] \quad (\text{A6})$$

$$T_{LO}(0) = T_{LO}^0$$

Appendix B

Most parameters in our numerical model, including those presented in the Appendix A, originate from Nordhaus and Yang (1996). As our regions do not fully correspond to those of Nordhaus and Yang (who use a more disaggregated framework), the parameters in our model are weighted averages of those used by Nordhaus and Yang, where each weight is defined as the size of the underlying variable in each country in the original model relative to the size of this variable in our regional framework. Our model also introduces additional structure, and the new parameters are

$$\rho = 0.8 \quad \gamma^n = 0.3 \quad \gamma_t^s = 0.3 \quad \gamma_i^s = 0.1 \quad \zeta = 0.001 \quad \alpha_2^n = 2.15 \quad \alpha_2^s = 2.15$$

$$\delta_k = 0.1$$

Table 4: Time varying parameter values

Period [*]	$\alpha_1^n(t)$	$\alpha_1^s(t)$	$\sigma^n(t)$	$\sigma_f^s(t)$	$\sigma_i^s(t)$
1	0.170	0.130	0.205	0.546	0.670
2	0.134	0.091	0.181	0.451	0.383
3	0.107	0.067	0.162	0.390	0.233
4	0.088	0.051	0.147	0.348	0.150
5	0.073	0.040	0.135	0.316	0.101
6	0.062	0.033	0.124	0.290	0.070
7	0.053	0.028	0.115	0.269	0.051
8	0.046	0.024	0.107	0.249	0.037
9	0.041	0.021	0.101	0.230	0.028
10	0.036	0.019	0.094	0.212	0.022
11	0.033	0.017	0.089	0.193	0.017
12	0.030	0.016	0.084	0.172	0.013
13	0.027	0.015	0.079	0.149	0.010

* Ten year periods

The parameters associated with the CO₂ emissions/output ratio (σ^n , σ_f^s) are calibrated such that the total emissions and temperature paths for the North and South in our baseline scenario closely tracks the corresponding paths in Nordhaus and Yang (1996). The emissions/output ratio for the informal sector (σ_i^s) is composed of the exogenous land use emission path from Nordhaus and Yang. The parameters of the cost functions (α_1^n , α_1^s) are calibrated such that the total emission reductions in our cooperative equilibrium correspond to the emission reductions in the corresponding scenario analyzed by Nordhaus and Yang.

Appendix C

Figure 1.
Industrial Emissions per region, reference case

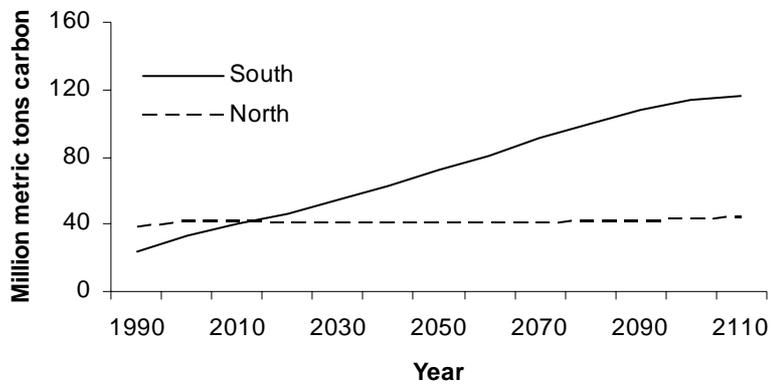


Figure 2.
Cost of the Technology Transfer, uncontrolled market economy supplemented with the Kyoto restriction

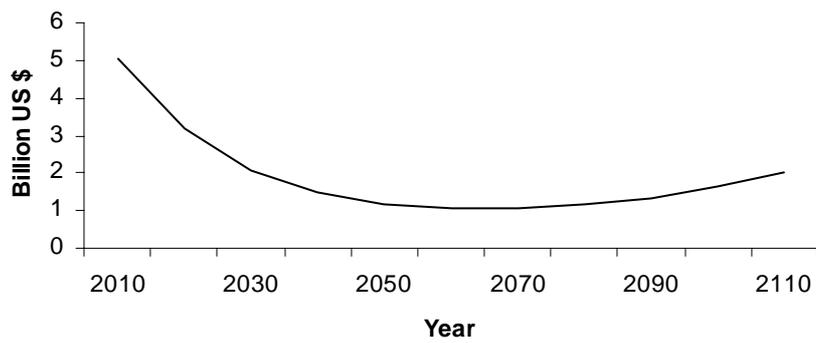


Figure 3.
Industrial emissions per region, cooperative equilibrium

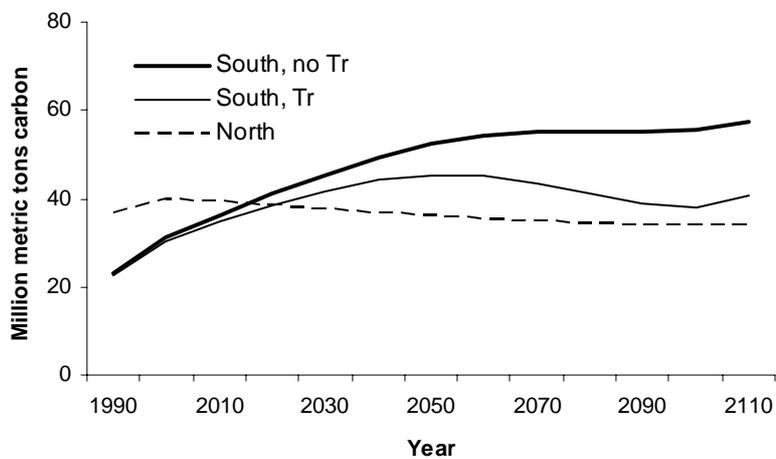


Figure 4.
Transfer in per cent of GDP, cooperative equilibrium

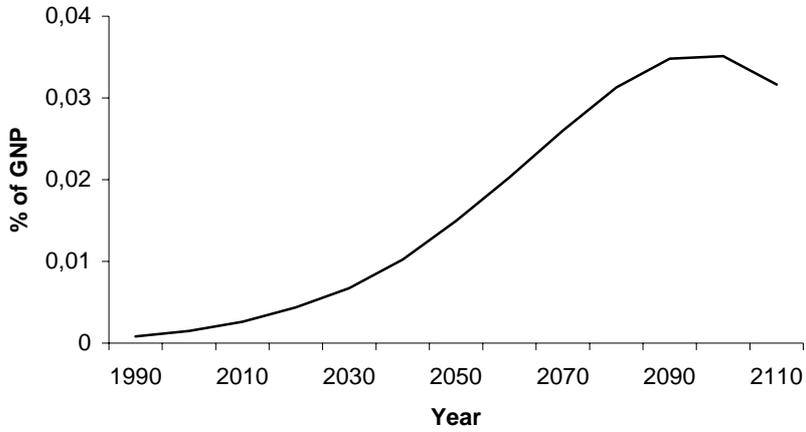


Figure 5.
Cost of the transfer, cooperative equilibrium

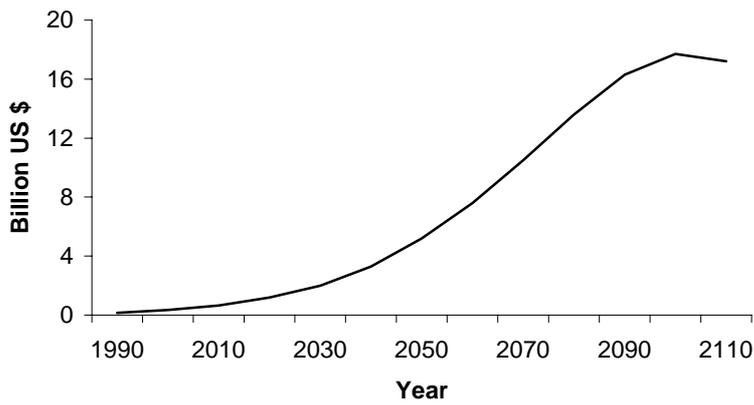
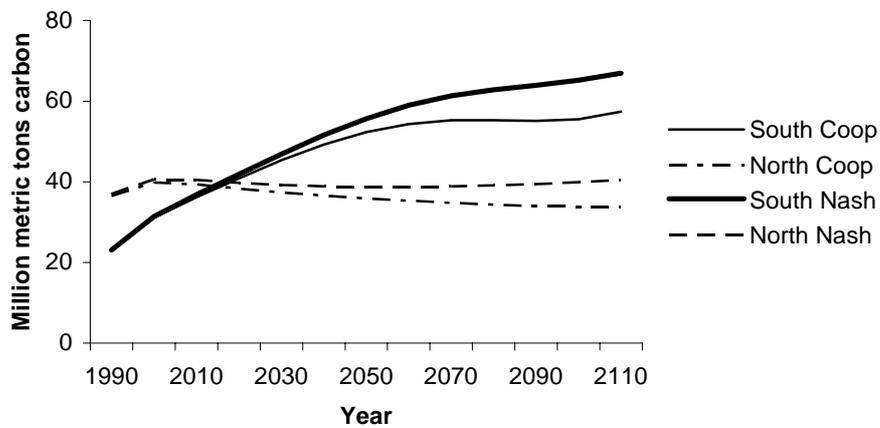


Figure 6.
Industrial Emissions, Cooperative and Nash Equilibrium, Tr = 0



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Tables

Table 1: Imperfectly Controlled Market Economies

Scenario	Tr	Δ Temp	PVC _N	PVC _S	PVC _{TOT}
Reference case	-	2.463	-	-	-
Kyoto					
<i>Tr</i> not available	-	2.409	-0.392	0.578	0.186
<i>Tr</i> available	Yes	2.409	0.152	0.621	0.773

*PVC is the present value of future consumption. Each such number is measured by comparison with the reference case, i.e. we subtract the number for the reference case. Trillion US 1990 \$.

Table 2: Cooperative Equilibrium

Scenario	Tr	Δ Temp	PVC _N	PVC _S	PVC _{TOT}
Baseline, μ_s free	-	2.098	0.642	2.106	2.749
<i>Tr</i> available, μ_s free	Yes	1.996	-0.219	2.991	2.773
<i>Tr</i> available, $\mu_s = 0$	Yes	1.990	-1.729	4.491	2.762

*PVC is the present value of future consumption. Each such number is measured by comparison with the reference case, i.e. we subtract the number for the reference case. Trillion US 1990 \$.

Table 3: Non-cooperative Nash equilibrium

Scenario	Tr	Δ Temp	PVC _N	PVC _S	PVC _{TOT}
Baseline, μ_s free	-	2.192	0.798	1.683	2.481
<i>Tr</i> available, μ_s free	No	2.192	0.798	1.683	2.481
<i>Tr</i> available, $\mu_s = 0$	Yes	2.362	0.243	1.015	1.258

*PVC is the present value of future consumption. Each such number is measured by comparison with the reference case, i.e. we subtract the number for the reference case. Trillion US 1990 \$.

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