Climate Policy and Development

- The Role of Technology Transfers and the Clean Development Mechanism in a North- South Model*

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Abstract

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). We consider three different pre-transfer resource allocations; (i) the regions behave as uncontrolled market economies, (ii) the regions behave as Nash competitors, and (iii) the pre-transfer resource allocation is a conditional cooperative equilibrium. 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 may affect the Southern economy. In the conditional cooperative equilibrium regime, where the resource allocation is decided upon by a global social planner, the welfare gain for the South of introducing a technology transfer outweighs the welfare loss for the North. However, if the regions do not cooperate prior to the introduction of the technology transfer, the incentives for the North of using this option appear to be relatively weak, at least if we allow for abatement efforts carried out by the South prior to introducing the transfer. By adding the requirement for emissions reduction implicit in the Kyoto protocol to the otherwise uncontrolled market economy, the results imply that the technology transfer leads to higher welfare for both regions.

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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 has explicit emission targets. The importance of cost-efficiency has been recognized by the UN Framework Convention on Climate Change (UNFCCC), Art. 3.3., which states that climate policy should "ensure global benefits at the lowest possible cost". In practice, this means that, although the emission targets are imposed only 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 possible way of increasing the cost-efficiency is to use technology transfers from the developed to the developing countries.[1] In addition, a technology transfer needs not only be a means of lowering the abatement cost; it may also contribute to productivity and economic growth in the developing countries.[2] However, despite strong commitments by the UNFCCC and Agenda 21 to the idea of technology transfers already in 1992, technology transfers have so far only played a minor role.[3] In the light of these observations, the purpose of this paper is to analyze the welfare effects of such 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 has been operationalized via the "Clean Development Mechanism" (CDM), which allows the Annex I countries to invest in projects aimed at reducing the emissions in developing countries and offset some of their own emissions against the savings from 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

[1] See Grubb (2000) and Forsyth (1999).
[2] The idea that pollution control equipment can lead to cleaner and more efficient processes was first established by Porter. See e.g. Porter (1991).
[3] See Forsyth (1999); while other investment flows from the industrial to the developing countries may have increased the amount of investment in environment- and development is low.

targets".[4] Earlier studies typically address the CDM in a way similar to emissions trading, while at the same time adding the assumption of a more limiting supply of permits from the developing countries.[5] However, if the CDM is formalized in this particular way, the first part of the purpose (to assist non-Annex I in achieving sustainable development) is not explicitly recognized.[6] Another aspect of relevance for our analysis is that the 'non-carbon welfare effects' associated with the CDM are potentially very important for the developing countries, when they decide on whether or not to participate in projects aiming at emission reductions at the global level. 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.[7] By selecting projects in accordance with the priorities in the host countries, the CDM may lead to new investment flows and increase the magnitude of transfers of technology and know-how. Therefore, the role of technology transfers is often emphasized in the discussion of future developments of the CDM.[8]

In this paper, we simulate the welfare effects of introducing a technology transfer in a world comprising two regions, North (Annex I countries) and South (non-Annex I countries). 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.[9] Clearly, the welfare effects of a technology transfer depend on the pre-transfer resource allocation. We consider three different regimes[10]; (i) the regions behave as uncontrolled (or imperfectly controlled) market economies – a regime which is also extended by allowing for the requirement of emissions reduction in the North due to the Kyoto protocol, (ii) the regions behave as Nash competitors, 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

[4] See Article 12 in the Kyoto Protocol.
[5] See Ellerman, Jacoby and Decaux (1998) and Zhang (2001).
[6] See Banuri and Gupta (2000); they argue that the CDM can be seen either as creation of market permits or as an inflow of resources, development and social progress.
[7] See Austin and Faeth (1999).
[8] See Forsyth (1999).
[9] See Nordhaus and Yang (1996).
[10] There is a large literature dealing with environmental and other policies in economies with transboundary environmental problems, where different aspects of noncooperative behavior are compared with the outcome of policy cooperation; see e.g. Aronsson et al. (2004) and Aronsson et al. (2006) as well as the references therein.

behave in the absence of cooperation. The first means that all external effects generated by each region remain uninternalized, whereas the second implies that each region internalizes the welfare effects facing the domestic residents (while the transboundary external effects 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. The noncooperative Nash equilibrium concept is also intuitively reasonable in the sense that it presupposes that each national government (and not just the private sector) has made an optimal policy choice (from its own perspective) prior to the introduction of the technology transfer, and that none of the regions is strong enough to act as a first mover. Although unrealistic from a (current) practical policy perspective, the conditional cooperative equilibrium regime is interesting for purposes of comparison, since it allows the preferences to 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 economies[11]. This enables us to capture the effects of labor mobility between the two sectors following a technology transfer. The formal sector is more capital intensive than the informal sector, and is therefore characterized by a higher average productivity. From the perspective of the North, the technology transfer from the North is motivated by the difference in abatement costs between the regions. In addition, a technology transfer can be thought of as an investment in terms of a new or more efficient abatement technology, which most likely increases the 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 other direct effect on the Southern economy than a reduction of greenhouse gas emissions; in other words, he did not address the productivity-oriented effect mentioned above. Our approach of modeling the transfer is a way

[11] See e.g. Ihrig and Moe (2000).

of capturing Southern ‘non-carbon’ benefits from possible CDM projects in a general equilibrium model.

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 model 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 of Nordhaus and Yang (1996) with the extensions mentioned in the previous section. In what follows, we use the following notations (neglecting the region specific superindex);

C	Aggregate consumption
N	Labor (population)
K	Capital stock
$c=C/N$	per capita consumption
I	investment level
μ	CO_2 emissions control rate
Tr	Technology transfer
E	CO_2 emissions
σ	CO_2 emissions/output ratio
T_E	Atmospheric temperature

Let us begin by describing the consumption part of the model. Each region is characterized by identical individuals[12] and a variable population. The objective function underlying public policy in each region is assumed to be utilitarian

$$U_0^j = \int_0^\infty N^j(t)\, u^j(c^j(t)) e^{-\theta t} dt \qquad (1)$$

[12] 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.

for $j = n, s$, where $u^j(\cdot)$ is the instantaneous utility function facing each resident and θ the utility discount rate. By analogy, the objective function underlying cooperative behavior, where the preferences characterizing both regions are recognized, is also utilitarian

$$W_0 = U_0^n + U_0^s \tag{2}$$

The instantaneous utility function takes the Cobb-Douglas form

$$u^j(c^j(t)) = [c^j(t)]^\rho \tag{3}$$

in which $\rho \in (0,1)$ reflects the degree of concavity of the instantaneous utility function.

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

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

where $\widetilde{A}^n(t) = A^n(t)[1 + \zeta^{ns}\mu^n(t)]$ represents the level of technology in period *t*, meaning that we allow for the possibility of 'abatement driven' technological change. The expression $\Omega^n(t) = 1/[1 + \theta_1^n TE(t) + \theta_2^n TE(t)^2]$ represents a production externality due to global warming. We will return to the assumptions about the fixed parameters γ, ζ^{ns}, θ_1^n and θ_2^n below. The part of output used for domestic private consumption becomes

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

in which $\omega(Tr(t))$ is the cost of the technology transfer, whereas $\alpha_1^n(t)$ and α_2^n represent 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 is the technology transfer. Capital formation is governed by

$$K^n(t) = (1-\delta)K^n(t-1) + I^n(t) \tag{6}$$

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

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

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

where the parameterization is analogous to that corresponding to the North, while $N^s = N_f^s + N_i^s$. The technology parameter in equation (7), i.e.

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

reflects the idea that the technological change in the formal sector is driven both by abatement (as in the North) and the technology transfer, whereas $A_i^s(t)$ in equation (8) is an exogenous and time dependent technology parameter in the informal sector. The term $\zeta^{ns} > 0$ is a fixed parameter to 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, part of output used for domestic private consumption is given by

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

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

$$K_f^s(t) = (1-\delta)K_f^s(t-1) + I_f^s(t) \tag{10}$$

$$K_i^s(t) = (1-\delta)K_i^s(t-1) + I_i^s(t) \tag{11}$$

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

$$E(t) = E^n(t) + E_f^s(t) + E_i^s(t) \tag{12}$$

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

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

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

$$E_i^s(t) = \sigma_i^s(t)Q_i^s(t) \tag{15}$$

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 data and parameters from the RICE-99 and DICE-99 economic models of global warming.[13] From the original RICE-99-model with 13 regions, Japan, USA, Europe, other high income countries, Russia and Eastern Europe are aggregated into region North. The North can also be called the "Annex I", because it contains all countries which are subject to emission targets in the Kyoto protocol.[14] 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 no commitments to reduce their emissions in the Kyoto Protocol. The base year in our model is 1990, and the time horizon is 20 periods, where each period represents one decade. Following Nordhaus and Yang (1996), we have chosen to concentrate part of the analysis on a shorter interval of the time horizon, in our case, more exactly on the first 13 periods (1990-2110). The welfare analysis for each of the three regimes is conducted by using all 20 periods.

[13] See Versions 020899, available at http://www.econ.yale.edu/~nordhaus/homepage/homepage.htm.
[14] A list of the Annex I countries can be found in the Kyoto Protocol. Out of these 40 countries, only USA, Australia and Monaco had not yet ratified the Protocol the 6th of February 2006.

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 emission control 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 be possible for the North to capture the "low-cost" alternatives of abatement in the South, if there is a chance that the abatement from the project in question would have been implemented even without the CDM.[15]

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 low developed countries averages 0.39, while the corresponding share in the OECD is only about 0.14.[16] This leads to more uncertain estimates of the actual GDP level in developing countries. We assume there is an additional 'hidden' informal sector of the size of about one third of the production in the formal (observed) sector in the southern economy. In the beginning of the time span, the informal sector is of the size of one third of the regional equivalent to GDP in the formal sector; however, the informal sector then shrinks over time as the southern economy develops. The informal sector is more labor intensive than the formal sector, and the average productivity is lower than in the formal sector.

We assume that the production in the formal sector corresponds to the observed regional equivalent to GDP, and that the industrial emissions of the South are equal to the observed levels in the beginning of the planning period. The observed industrial emissions are associated with the formal sector; this means assuming that there are no large industries in the informal sector. However, there is also another source of emissions, which is treated as

[15] See Article 12 in the Kyoto Protocol.
[16] See Ihrig and Moe (2000).

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.[17] Realizing the fact that a sector without large industries still 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, the informal sector emissions decrease over time in a way similar to the path for the exogenous land-use emissions in the original RICE99 and DICE99 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 production has to 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 investment in abatement technology. For the southern economy, both domestic abatement and the technology transfer will affect the level of total factor productivity.[18] This productivity effect from the technology transfer gives rise to labor mobility from the informal to the formal sector in the South. This implies increased output in the Southern formal sector, which might also lead to higher emissions.

Our choices of parameter values for the North-South model, together with a sensitivity analysis for the new important parameters, are described in the Appendix C.

4. Simulation results

In this section, we present the results from simulations based on the numerical general equilibrium model described in Section 2. 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 emission targets in the Kyoto protocol, (ii) the resource allocation is a cooperative equilibrium, and (iii) the resource allocation is a

[17] See IPCC (2001).
[18] This resembles the so called ‘Porter-hypothesis’; see Porter (1991).

noncooperative Nash equilibrium in open-loop form. The comparison refers to the present value of future consumption in each region as well as at the global level, which are easily calculated and observable indicators. Note also that the three regimes only differ with respect to environmental policy; we do not incorporate factor mobility between the two regions into the analysis. This enables us to concentrate on environmental policy aspects in a simple way and is also in line with earlier, comparable, research. Equilibrium paths for key variables are presented in the Appendix D. 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 three types of resource allocations described above, we present results from a baseline simulation, where the option of using the transfer is not available, as well as relate the incentives of using the transfer to whether or not the South is carrying out abatement prior to the introduction of the transfer.

4.1 Imperfectly Controlled Market Economies

Table 1: Imperfectly Controlled Market Economies

Here

The uncontrolled market economy is a projection of what would happen if no governmental action is taken to slow down the global warming. Emissions are simply seen as a side effect of production, meaning that the welfare effects of these emissions are not incorporated into the decision problems. In this case, the global temperature increase by the year 2110 is simulated to be 2.480 degrees Celsius[19]. The emission paths for each region can be seen in Appendix D1.[20] Interesting to note is that, within a few decades, the South will be the main emitter of carbon dioxide, while the simulated emissions path for the North is relatively constant. However, in terms of carbon emissions per capita, the South will not reach the level of the North during the whole simulation period.

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%

[19] The measure of temperature, in degrees Celsius, is the temperature increase in period 13 compared to a pre-industrial base temperature level.
[20] This result is in line with the baseline scenario in the RICE- and DICE- models, versions 020899.

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 for ever. With the Kyoto restriction, the temperature is estimated to be 2.423 degrees Celsius, whereas the temperature increase in the uncontrolled market economy (our reference case) is 2.480 degrees Celsius. This confirms other studies' results that the Kyoto protocol will only have a modest effect on global warming. 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. This implies that the total wealth effect from the Kyoto protocol is positive.[21]

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 549 billion US \$.[22] As such, this gives an indication of the potential gains for the North of using the CDM. The welfare gains for the South are mainly explained by the direct productivity increase accompanied by labor mobility from the informal to the formal sector. The size of technology transfer, given the emission reduction targets in the Kyoto protocol, is shown in Appendix D2.

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 is implemented) with the observed level of funding for such climate projects in 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 on such projects during that time period.[23] This may either imply that our model exaggerates the

[21] In our model, the North comprises all Annex I countries; also USA, Australia and Monaco, which have not yet ratified the protocol. An exclusion of, in particular, the USA, might imply an even smaller welfare effect of the Protocol.
[22] As the amount of transfer depends on the level of domestic abatement already implemented in the South, it is interesting to note that even if the South would choose a control rate level as in a Nash equilibrium, the North would still find it profitable to use a technology transfer (although a smaller amount) to reach the Kyoto target.
[23] See Michaelowa (2000); According to the Global Environment Facility (GEF), the flow of money for climate projects between 1991-1997 disbursed around 0.7 billion US $ (about 45 % of the total projects).

incentives to use the technology transfer, or that the CDM has not yet been used up to its full potential.

4.2 The Cooperative Equilibrium

These scenarios are 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 costs and benefits of emission control balance at the global level. The latter is the aspect of cooperation that we would like to capture; we are not assuming that the regions pool all their resources, since we disregard factor mobility between the regions.

Table 2: 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 consumption is higher in both regions than in the reference case (the uncontrolled market economy), and the temperature increase becomes 2.145 degrees Celsius.

Let us now turn to the second row of Table 2. By introducing the option of using the technology transfer as a means of increasing the cost-efficiency in the abatement policy, our results imply that this option will be used during the entire simulation period. This leads to higher wealth at the global level measured by the present value of future consumption. The optimal emission control rates for the North and South do not change much in comparison with the baseline simulation. Therefore, by introducing the technology transfer, we are able to reduce the emissions. Interestingly, this scenario makes the North worse off than in 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 mainly due to the productivity increase accompanied by labor mobility from the informal to the formal sector.

If we impose the restriction that the emission control rate for the South should be equal to zero (the third row in Table 2), this leads to a larger technology transfer than in the previous scenario, where the emission control rate for the South is chosen freely by the global social planner. Although somewhat artificial, this scenario is interesting in the present context, since we do not pool all the resources between the regions; it also simplifies the comparison with the result presented in the next subsection. Note that the emission control rate for the North does not change significantly; and the considerable amount of transfer brings the Southern industrial emissions to almost the same level as in the previous scenario. The North becomes worse off, even in comparison with the uncontrolled market economy, while the South becomes much better off. The emission paths are shown in the Appendix D3. 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 Appendix D4, 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 US $ in the first time period, to 17 billion US $ in period 13, which is also shown in Appendix D5. Both the cost and the share of the transfer in the regional equivalent to GDP increase during the simulation period. Our model implies a smaller technology transfer than found by Yang (1999)[24]. Except that the North and South in our model do not include exactly the same countries as the corresponding regions in Yang's model, the 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 difference in marginal cost of abatement between the regions. Notice that these figures for the amount of transfer are based on the scenario, where the emission control rate of the South is positive. If, on the other hand, we consider the scenario where the emission control rate of the South is not an available option for the global social planner[25], the results change dramatically. Therefore, in our model, the assumptions about abatement policy options in the South are of considerable importance for the optimal size of the technology transfer. The size of the transfer in the latter case ranges from 2 billion US $ in the first period up to 433 billion US $, which is considerable higher than in the corresponding scenario in

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[24] The optimal amount of transfers in the corresponding scenario in Yang's model ranges from about 1 billion to 80 billion US $.

[25] This could be the case, if for some reason the option of a positive emission control rate of the south does not exist or if the Global Planner is of the opinion that the South is "too poor to pay".

Yang's model. One reason why our transfer is higher in this case, is the extra positive effects on the southern economy (remember that, in the cooperative equilibrium, the preferences of both North and South govern the decision of optimal policy).

The optimal size of the transfer in terms of the model may also be compared with the actual resources spent on this type of climate projects between 1991 and 1997. The transfer in the first period of our optimal scenario is higher than the corresponding level of resources actually spent on such projects. In the case when the southern control rate equals zero, the transfer in our model is significantly higher than the observed levels of climate projects.

4.3 The Non-Cooperative Nash Equilibrium

These scenarios have in common 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: Non-Cooperative 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 – 2.233 degrees Celsius – in comparison with the corresponding cooperative resource allocation. At the same time, note that the difference in the present value of future consumption is relatively small at the global level; the difference between, on the one hand, these two scenarios 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.

Consider next 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 make any transfer to the South. Although the transfer increases the welfare at the global level, the North would become worse off by using the transfer. Therefore, the results are equivalent to those discussed above. This result is not surprising; the abatement by the South reduces the abatement cost difference between the regions. If, on the other hand, the emission control rate of the South is restricted to equal zero prior to the transfer, then the North will choose to make a transfer to the South in the Nash equilibrium; the abatement cost difference is much greater in this case. However, the present value of future consumption is significantly smaller at the global level in this case, since the size of the transfer chosen by the North will not be near the size of the emission control rate chosen by the South in the other scenario. The difference between the industrial emissions in the cooperative and the Nash equilibrium is shown in Appendix D6.

5. Conclusions

This paper deals with the consequences of introducing a technology transfer from North to 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 emissions and increases the 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 week from the perspective of the North. The reason is that Southern abatement 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, carry out the technology transfer to the South. The intuition is that the abatement cost differential between the regions is 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 slow its own emissions, it would be 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 the 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 citizens 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. Furthermore, if the global social planner for some reason is unable to abate emissions originating from the South, it would be welfare improving for the world as a whole if the North pays for the abatement of Southern emissions.

Given the Kyoto Protocol, with the goals of cost-efficiency and equity, the Annex I countries (which have ratified the protocol, i.e. not USA, Monaco and Australia), have accepted to be leaders by starting to reduce their industrial emissions, while for the developing countries, there are yet no such commitments. There is hope that the emission reductions in the Kyoto protocol in combination with the CDM leads to cost-efficient abatement as well as provide greater incentives for the North of speeding up the transfer of technology to the South. In the context of our model, we use the reference scenario, where the regions are uncontrolled market economies, and then introduce the Kyoto protocol restriction along with the possibility for the North of using the technology transfer. Our results show that, given the Kyoto Protocol, the North will benefit from using the technology transfer. 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. Therefore, given the assumptions in this model, if the CDM is designed as a technology transfer, it may contribute to cost-efficient abatement from the perspective of the North and economic development in the South.

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Tables

Table 1: Imperfectly Controlled Market Economies

Scenario	Tr	Δ Temp	NEI*$_N$	NEI*$_S$	NEI*$_{TOT}$
Reference case	-	2.480	-	-	-
Kyoto, no transfer, $\mu s = 0$	-	2.423	-0.397	0.491	0.094
$\mu s = 0$	Yes	2.423	0.152	0.533	0.685

*Net economic impact, measured as the present value of consumption for different scenarios compared to the uncontrolled market economy. Trillion US 1990 $.

Table 2: Cooperative Equilibrium

Scenario	Tr	Δ Temp	NEI*$_N$	NEI*$_S$	NEI*$_{TOT}$
Baseline, μs free	-	2.145	0.625	1.610	2.235
Tr available, μs free	Yes	2.042	-0.150	2.390	2.240
Tr available, $\mu s = 0$	Yes	2.042	-1.354	3.587	2.233

*Net economic impact, measured as the present value of consumption for different scenarios compared to the uncontrolled market economy. Trillion US 1990 $.

Table 3: Non-cooperative Nash equilibrium

Scenario	Tr	Δ Temp	NEI*$_N$	NEI*$_S$	NEI*$_{TOT}$
Baseline, μs free	-	2.233	0.727	1.293	2.020
Tr available, μs free	No	2.233	0.727	1.293	2.020
Tr available, $\mu s = 0$	Yes	2.375	0.245	0.877	1.122

*Net economic impact, measured as the present value of consumption for different scenarios compared to the uncontrolled market economy. Trillion US 1990 $.

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

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

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

$$\begin{aligned} M_{UP}(t) = {} & b_{22}M_{UP}(t-1) + b_{12}M_{AT}(t-1) - b_{21}M_{UP}(t-1) \\ & + b_{32}M_{LO}(t-1) - b_{23}M_{UP}(t-1) \end{aligned} \tag{A2}$$

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

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

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

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

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

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

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

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

Appendix C

Most parameters in our numerical model, including the parameters in Appendix A, are taken directly from Nordhaus and Yang (1996). The parameters connected to each region are either treated as weighted averages or aggregated into our regions North and South. The new parameter values in our aggregated model of North and South are:

$\rho = 0.8$ $\gamma^n = 0.3$ $\gamma_f^s = 0.4$ $\gamma_i^s = 0.2$ $\zeta^{ns} = 0.001$ $\alpha_2^n = 2.15$ $\alpha_2^s = 2.15$
$\delta_K = 0.1$

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	0.690
2	0.134	0.091	0.181	0.451	0.428
3	0.107	0.067	0.162	0.390	0.281
4	0.088	0.051	0.147	0.348	0.194
5	0.073	0.040	0.135	0.316	0.139
6	0.062	0.033	0.124	0.290	0.103
7	0.053	0.028	0.115	0.269	0.078
8	0.046	0.024	0.107	0.249	0.061
9	0.041	0.021	0.101	0.230	0.048
10	0.036	0.019	0.094	0.212	0.038
11	0.033	0.017	0.089	0.193	0.031
12	0.030	0.016	0.084	0.172	0.025
13	0.027	0.015	0.079	0.149	0.020

* Ten year periods

The parameters for the CO_2 emissions/output ratio (σ^n, σ_f^s) are calibrated so that the total emissions- and temperature paths for 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 emissions path from Nordhaus and Yang (1996). The parameters of the cost functions (α_1^n, α_1^s) are calibrated so that total emission reductions in our cooperative scenario correspond to the optimal reductions in Nordhaus and Yang (1996).

Sensitivity Analysis

A sensitivity analysis has been conducted for some of the most crucial parameter-values in our model. There are no significant changes in the results for small adjustments of the production-function parameters γ_f^s and γ_i^s. Even if γ_f^s takes the value of 0.3 instead of 0.4, there will still be a movement of labor from the informal to the formal sector. Further, the larger the size of the technology effect from abatement, i.e. the parameter ζ^{ns}, the larger will be the movement of labor between the sectors, and the larger also the welfare effects associated with the technology transfer. However, a small value of these parameters is enough to identify the effect of labor mobility between the sectors. Our results do not seem to be very sensitive to the relative emissions to output ratio between the formal and informal sectors. Even if these region specific parameters would be more equal, the movement of labor, and thereby the positive welfare effect, would still appear.

We have also conducted a sensitivity analysis for the parameters in the damage functions for each region. The damage for the regions from a temperature increase of 2.5 degrees C is about 1 percent of GDP for the North and about 2 percent for the South, corresponding well with the damage in the original DICE and RICE-models. As the damage functions in the original models are associated with uncertainty, especially for the Southern region, we have studied how the results in our model would change for a doubling of the damage in each region. The main difference is that the optimal technology transfer gets larger, as well as the welfare effects from using the transfer. In the optimal scenario, the net economic impacts, measured as the present value of consumption, more than double when the damages are twice as large. Concerning the Nash equilibrium, the North will still not use the technology transfer as long as the Southern control rate is positive.

Appendix D

Figure 1.
Industrial Emissions per region, reference case

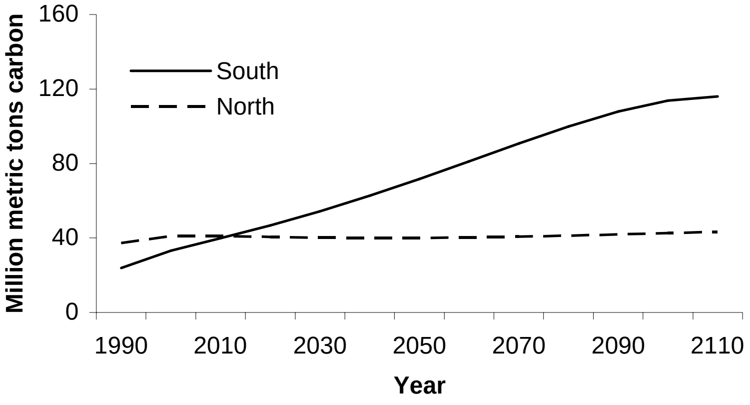

Figure 2.
Amount (costs) of Transfers, given the Kyoto restriction

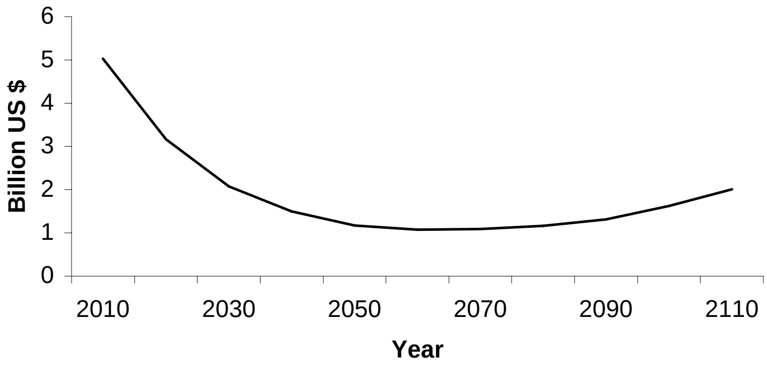

Figure 3.
Industrial emissions per region, cooperative scenario

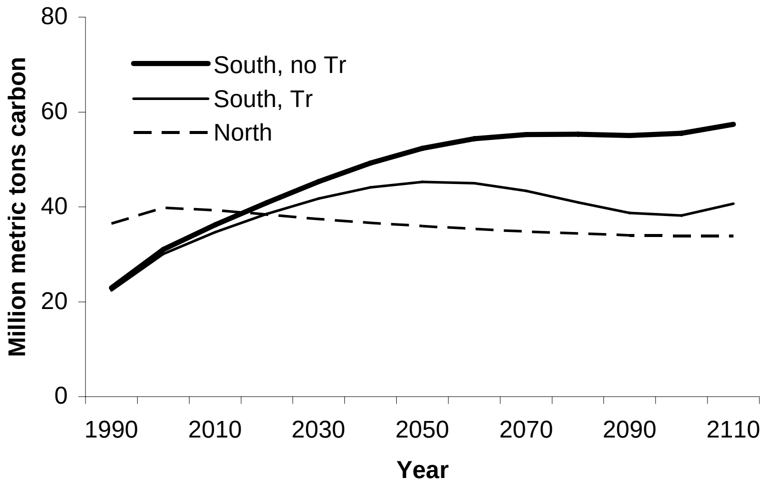

Figure 4.
Share of Transfers in % of GNP, Cooperative scenario

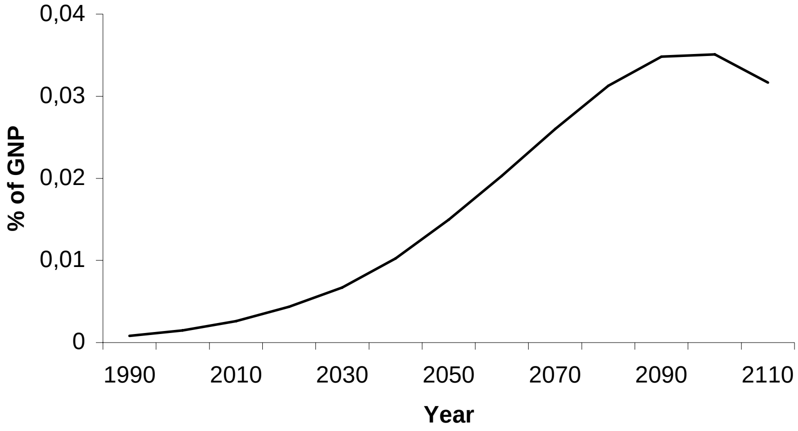

Figure 5.
Amount (costs) of transfers in the cooperative scenario

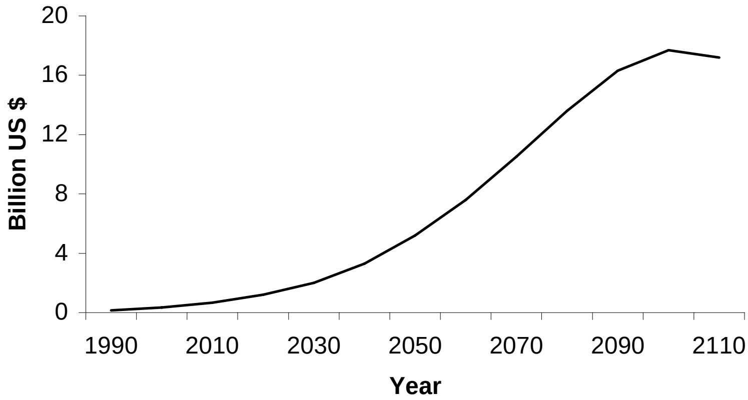

Figure 6.
Industrial Emissions, Cooperative and Nash Equilibrium, Tr = 0