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Magnitude and direction of technological transfers for mitigating GHG emissions[☆]

Zili Yang [*], William D. Nordhaus

Yale University and SUNY Binghamton, USA

Abstract

This paper discusses the issues of technological transfers aimed at reducing GHG mitigation costs under various assumptions. In a new version of RICE model, we introduce technological transfer mechanism that donors' monetary transfers go to recipients' GHG mitigation. Through such transfer mechanism, we examine the relationships between magnitude/direction of transfers and choice of social welfare weights in the model. Our simulations show that different social welfare weights may lead to significant shifts on magnitudes even directions of technological transfers. The results suggest that proposing policies of technological transfers should be mindful of distributional aspects and modeling assumptions.

Keywords: Climate change; Technological transfers; Integrated assessment modeling

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1. Introduction

Dealing with climate change is an internationally cooperative undertaking. Countries face different consequences from potential global warming. They also adopt different technological approaches and incur various amounts of mitigation costs, if they choose to do something about climate change. Industrialized countries possess more advanced technologies of GHG mitigation; they also have more economic interests at stakes from GHG mitigation, despite technological edges. Therefore, transferring GHG mitigation technologies from industrialized countries to less-developed countries is an attractive policy option. In IPCC WGIII TAR (IPCC, 2001), both direct financial transfers and technological transfers are listed as potential policy tools. Scholars studied

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[*] Corresponding author.
E-mail address: zlyang@binghamton.edu (Z. Yang).

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transfer issues from different perspectives: from inducing incentives to form international cooperation (Chander and Tulkens, 1997; Petrakis and Xepapadeas, 1996) to evaluating transfers' roles in implementing climate change policies (Hahn and Stavins, 1995; Montgomery, 1997). Transfers, mainly modeled as channels for financial flows, are also built into large Integrated Assessment models developed by various research groups, such as MIT's EPPA model (Jacoby et al., 2004) and the Pacific Northwest National Laboratory's SGM model.

In this paper, we investigate technological transfer issues in RICE framework. Specifically, we propose a modeling approach, which properly characterizes technological transfers, and implement such mechanism in the RICE model. In this approach, we allow technological flows across regions for GHG mitigations. Our simulations demonstrate that it requires meticulous modeling efforts to differentiate financial and technological transfers in an IAM. Furthermore, we show that reasonable and correct magnitude and directions of technological transfers can only be modeled by using the Negishi social welfare weights.

Next, we discuss briefly the needs for separating financial and technological transfers in the integrated assessment, as well as the modeling approach to be followed in this paper. In Section 3, we introduce the new RICE model and the experiment designs. Section 4 describes and analyzes the major simulation results. Section 5 examines ramifications of technological transfers through additional simulations. Section 6 contains concluding remarks.

2. Technological transfers in IAMs

International monetary flows always accompanied by mirroring material flows. Setting up a mechanism for technological transfers from industrialized countries to less-developed countries, we expect that either the recipient regions use the monies to pay for GHG mitigation using indigent technologies, or they use the monies to import advanced GHG mitigation technologies from donor regions. Accurately speaking, technological transfers should refer the latter case.

If the recipient regions receive pure financial transfers, they could use the monies for any purposes. In real life, much of the transfers for whatever noble courses ended up in the coffers of dictators and corrupt government officials of recipient countries. In economic models, direct financial transfers will go to the sectors that can enhance the recipients' utilities most efficiently. Therefore, financial transfers in real life and in economic models cause wealth and income effects, often distorted ones.

Because of its simplicity, only involving a global flow constraint (sum of outflows = sum of inflows), financial transfers are easy to capture in an IAM. However, the (endogenous) forces to generate financial transfers vary in different models. Often times, it is difficult to separate wealth effects and the impacts of the transfers on GHG mitigations. Although such an approach is widely adopted in IAMs, we believe, as our simulations will show, that it is full of caveats.

In this paper, we introduce an alternative modeling approach that focuses on technological transfers and implement the approach in the RICE model. The mechanism allows transfers for GHG mitigations but not for wealth redistribution. In this framework, there are two categories of regions in the world: one is donors; another is recipients. The donors make unilateral transfers of GHG mitigation technologies to the recipients. As the results, the donors' GDP reduce directly and they are compensated indirectly (and probably fully) through the spillover effects of GHG mitigation from the recipient regions. On the other hand, the recipients' GDP are not affected directly by such transfers. Thus, we have the following:

$$\mathrm{GDP}_i(t) = C_i(t) + I_i(t) - \mathrm{Tr}_i(t) \qquad \text{(donor regions)} \tag{1}$$

$$\mathrm{GDP}_j(t) = C_j(t) + I_j(t) \qquad \text{(recipient regions)} \tag{2}$$

The technological transfers from all donors are homogenous. They are pooled before flow to recipient regions:

$$\mathrm{Tr}A(t) = \sum_{i=1}^{m} \mathrm{Tr}_i(t) \tag{3}$$

Each recipient region receives a share of aggregate transfers:

$$\sum_{j=1}^{n-m} \theta_j(t) = 1, \qquad \theta_j(t) \geq 0. \tag{4}$$

The transfers of GHG mitigation technologies add to GHG mitigation capacity and activities of the recipient regions. In the RICE model, such activities are represented by additional GHG control rates. The level of the control rate is determined by the domestic GHG mitigation cost function at the margin. Namely, $v_j(t)$, the control rate from technological transfers, can be expressed as,

$$v_j(t) = \theta_j(t)\mathrm{Tr}A(t)/[Y_j(t)\mathrm{Cost}_j(t)] \tag{5}$$

Finally, the actual GHG emissions in the recipient regions are baseline ("business-as-usual") level minus the domestic mitigation (if any) and the mitigation from technological transfers.

$$E_j(t) = \sigma_j(t)Y_j(t)[1-\mu_j(t)-v_j(t)] \tag{6}$$

In the above mechanism, $\mathrm{Tr}_i(t)$ and $v_j(t)$ are control variables. The social planner decides who donates and who receives, and how much. If any technological transfer occurs, it improves global welfare through GHG mitigation, not through income redistribution. Such an approach should capture the incentives, or willingness to pay, of the donors. We plan to implement such technological transfer scheme in the RICE model. However, to demonstrate technological transfers correctly in IA models, we need additional assumption and meticulous modeling works. We will see these procedures in the next section.

After identifying and modeling the technological transfer problem correctly, we hope to answer some important policy questions regarding technological transfers. Who will donate, to whom and by how much? Do technological transfers improve the world welfare, compared with other policy alternatives?

3. The new rice model and experiment design

The model we used for the simulations is based on a new version of the RICE model, labeled as RICE2004. The new model evolves from its two predecessors, the original RICE model (Nordhaus and Yang, 1996) and RICE-99 (Nordhaus and Boyer, 2000). The development of RICE2004 is underway. We briefly summarize the main feature of RICE2004 below.

The model contains eight regions. They are USA, EUROPE, OHI (Other high-income countries), EE (Eastern European countries and former Soviet Union), MI (Middle-income countries), CHINA, LMI (Lower middle-income countries), and LI (Low-income countries). The regional breakdown is consistent with RICE-99 (see Nordhaus and Boyer (2000) for details). The time step of RICE2004 is a 5-year period, for 60 periods. In this set of experiments, we shorten the time span to 40 periods.

In essence, RICE2004 is a multi-region optimal growth model with climate externalities. Programmatically, the model can be expressed either as an optimal control problem for efficient provision of GHG emission (a social planner's problem) or as an open-loop Cournot–Nash game for inefficient equilibrium solution. In both solution concepts, regions decide private investments, $I_i(t)$, (for growth) and public investments, $\mu_i(t)$, (for controlling climate externality) simultaneously. The tradeoffs between investing or not investing in GHG mitigation are mitigation costs and climate damages. In the simulation here, there is an additional set of control variables of giving and receiving technological transfers.

To study technological transfer issues, we only need the efficient solution concept. In an efficient scenario, we solve a social planner's problem in which climate externalities are fully internalized. The social planner maximizes a global welfare function consisting of weighted sum of regional welfare functions. It is a well-known fact that selection of social welfare weights has very significant distribution implications. If financial transfers were allowed in such a setting, the money would flow from rich regions to poor regions because a dollar at margin in poor regions will increase the social welfare function more than it does in rich regions. As we indicated before, such an outcome is exactly what we want to avoid.

The prevailing practice in choosing social welfare weights is to pick the utilitarian weights. Namely, each region is given to an equal weight. Such a weight selection is easy to implement. In addition, utilitarian weights have straightforward justification normatively. However, there will have huge amount of monetary flows among regions under the utilitarian weights. It just likes a group of inter-connected reservoirs with different water levels. Once the floodgates are open, water will flow from high to low levels.

In previous versions of RICE models, we adopted the time-variant Negishi social welfare weights to overcome the above-mentioned difficulties. For this purpose, we have developed an iterative algorithm for searching the time-variant Negishi weights. The Negishi weight is an important concept in general equilibrium theory. When a social planner's problem is solved under the time-variant Negishi weights, the shadow prices of capitals across regions are equalized in each period. Therefore, monetary flows across borders will not increase the social welfare and there is no incentive for the social planner to do so.

Investigating the direction and magnitude of technological transfers, we rely on the Negishi weights to isolate them from conventional financial transfers. To validate our methods and to compare the results, we also conduct simulations under the utilitarian weights. As we will see, the reasons for adopting the Negishi weights are more than necessary.

Our experiments consist of two sets of scenarios or cases. One is the benchmarks and basic scenarios of technological transfers (cases (i) to (v)); another is the ramifications and extensions of technological transfers (cases (vi) to (x)). All the scenarios are under the Negishi weights unless they are noted otherwise.

The five basic scenarios are:

(i) The "business-as-usual" scenario. In this scenario, GHG control rates and technological transfers are set at zero. The welfare levels and GHG emissions in this scenario serve as one of the benchmarks for comparison purpose.
(ii) The efficient scenario without technological transfers. This scenario serves as another benchmark for contrasting with technological transfer scenarios.
(iii) The quasi-"Kyoto" scenario. As specified in the Kyoto Protocol, some regions do not obligate to control GHG emissions. We set five regions' GHG control rate at zero. They

are EE, MI, LMI, CHINA, and LI. Under this condition, the social planner asks the remaining three regions, USA, OHI, and EUROPE to achieve the optimal GHG control rates.

(iv) The base case: quasi-“Kyoto”+technological transfers. This is the most likely scenario for technological transfers. In this scenario, USA, OHI, and EUROPE are donors and other five regions are recipients. The recipient regions will not control GHG emissions on their own. Their GHG mitigations, if any, are through technological transfers.

(v) The comparison case: (iv) and global GHG emission target set in (ii). In this case, we want to see what happens to achieve the efficient GHG emission level in (ii) through unilateral transfers.

The five extension scenarios are:

(vi) Case (ii)+technological transfers.

(vii) Case (iii)+technological transfers under the utilitarian weights. This scenario is essentially a counter-example for rejecting the use of utilitarian weights.

(viii) “The reversal of fortune” scenario. In this scenario, we swap the donors and recipients in (v). The case demonstrates that transfers cannot be arbitrary. They associate with a region’s technology level and domestic GHG mitigation costs.

(ix) The “progressive” scenario. In this case, EE joins the donors’ camp in (iv).

(x) Case (iv)+lower pure time preference. In this scenario, we set the pure rate of time preference at 2% per year instead of 3% default.

4. Baseline and technological transfers

The first three scenarios are benchmarks without technological transfers. Evidently, cases (i) results in the highest regional and global GHG emissions and case (ii) the lowest. Between no policy intervention (case (i)) and the ideal efficient outcome (case (ii)), there are spaces for other policy outcomes. Case (iii) is a policy scenario of unilateral actions, which bears some resemblance of the Kyoto Protocol.

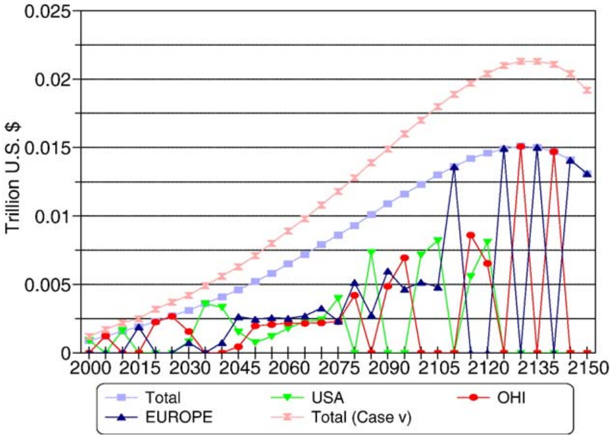

Fig. 1. Technological transfers.

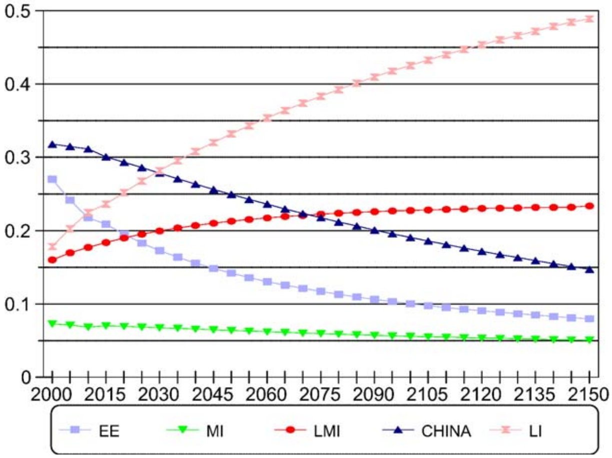

Fig. 2. Recipients' share.

To study the impacts of technological transfers, we simulate two technological transfer cases. Industrialized countries can transfer their GHG mitigation technologies to those regions with no GHG mitigation obligations, if they consider that unilateral actions are not sufficient. This idea motivates case (iv). In addition, case (v) investigates the welfare impacts of unilateral actions with technological transfers. To achieve the same GHG emission target as in the efficient outcome through technological transfers, it would have significant effects on both donors and recipients.

Under the quasi-"Kyoto" assumption, as in scenario (iv), we observe moderate amounts of technological transfers. Fig. 1 plots the volume of such transfers over time. The transfer amounts start at 1 billion dollars and peak at 15 billion dollars. The level is lower than most other models predict because of absence of redistribution motivations. Fig. 2 depicts the recipients' shares of transfers. The pattern is reasonable: the region (LI) with lowest income and highest GHG

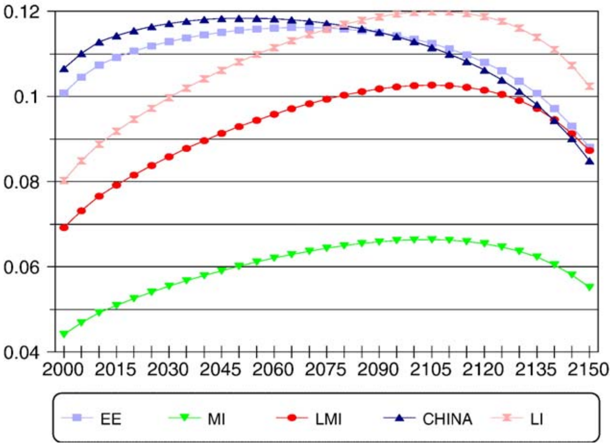

Fig. 3. GHG control rates from transfers.

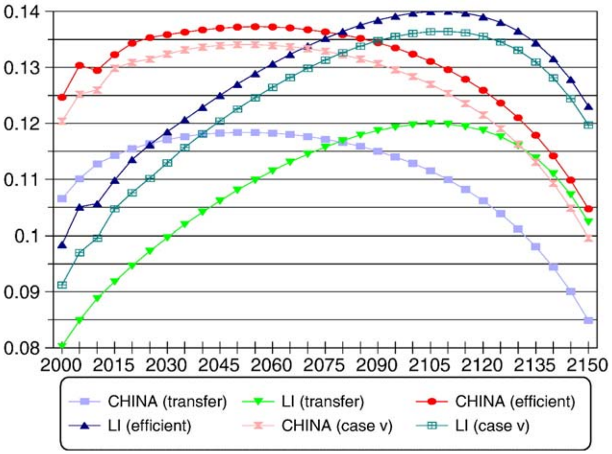

Fig. 4. GHG control rates.

emissions receives the largest share. Fig. 3 describes the GHG emission control rates of recipients generated by the technological transfers. They are between 5% and 10%. The patterns of control rates from transfers are similar to the domestic control rates in the efficient outcome without transfers (scenario (ii)) and the rates are higher in the transfer case. Fig. 4 compares the patterns of control rates for CHINA and LI between the two scenarios.

The technological transfers have marginal impacts on the domestic GHG control rates of the donors. The substitution effects between domestic GHG mitigation and technological transfers are minimal. Fig. 5 shows such effects in USA for selected years. Giving technological transfers reduces domestic control rates slightly.

Technological transfers in case (v) show similar patterns as in case (iv). To achieve the GHG emission target in case (ii), the most efficient strategy is to follow the control paths set in case (ii). However, if some regions do not initiate domestic GHG mitigations, technological transfer is probably the "second-best" option. For saving space and easy comparisons, we juxtapose

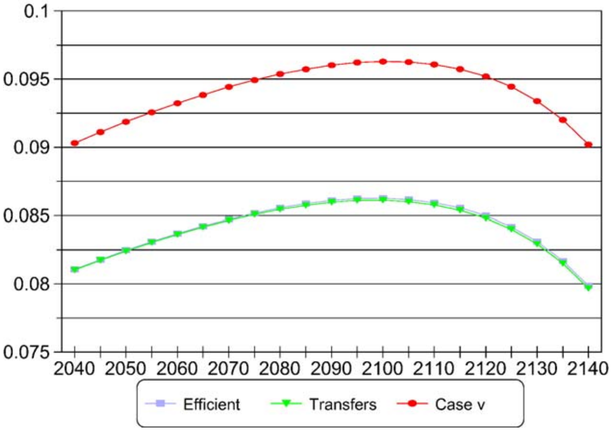

Fig. 5. Control rates substitution (USA).

selective results from case (v) in the graphs showing case (iv). They can be summarized as follows:

Efficient GHG emission target requires substantially higher technological transfers (Fig. 1). It demands much higher domestic GHG emission control from the donors. Fig. 5 shows what happens in the US. Finally, the recipients' control efforts from the transfers are near their domestic control efforts under the efficiency scenario. Fig. 4 shows the patterns for CHINA and LI. In sum, case (v) poses very heavy burdens on the donors by requiring higher domestic control and larger amount of transfers.

The welfare comparisons are complicated to offer a unified ranking, but patterns are predictable. We only compare scenarios (i) to (v). The global welfare has the following order, from low to high: BaU, quasi-"Kyoto", efficient emission target with transfers, quasi-"Kyoto" with technological transfers, and efficient without transfers. Alternatively, the ranking is (i), (iii), (v), (ii), and (iv) in case labels. The order is consistent with economic theories and the assumptions of the model. The regional welfares have the following patterns: everyone is better off in the efficient outcome than in BaU; everyone is better off in the efficient outcome than in quasi-"Kyoto"; recipients prefer quasi-"Kyoto" with transfers to the efficient outcome and quasi-"Kyoto"; and donors except OHI prefer quasi-"Kyoto" with transfers to quasi-"Kyoto." The losses of OHI in quasi-"Kyoto" with transfers are very small. The gainers from the scheme can easily compensate OHI's losses.

In presenting the welfare ranking, we do not attempt to answer the puzzle why the inferior unilateral action (quasi-"Kyoto") option is on the table. The issue is beyond this paper. However, we clearly suggest a welfare improving direction, namely, unilateralism plus transfers. However, if such unilateral action plus transfer is to meet some *ad hoc* target, both global and regional welfare might go down, just like case (v).

5. Extensions

To study the ramifications of technological transfer regimes, we also simulated cases (vi) to (x). They reveal some interesting results.

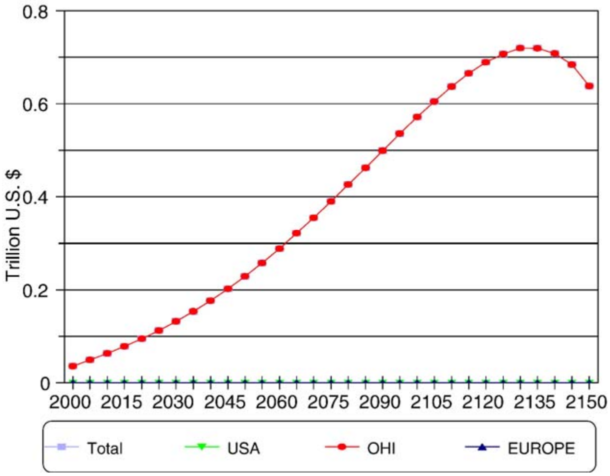

Fig. 6. Technological transfers (utilitarian weights).

First, if we allow technological transfers in the efficient solution with the Negishi weights, *no* transfers actually take place. The solution is not surprising because mitigation efforts are already allocated efficiently among the regions and further efforts in any region will not improve the global welfare. The motivation for technological transfers is to mitigate GHG emissions at the most effective locations. Since the carbon taxes across regions are equalized under the Negishi weights, there is no room for further improvement by transfers.

Secondly, the results from scenario (vii) are striking. The utilitarian social welfare weights cause strange outcomes. Fig. 6 shows the amounts and sources of the technological transfers. The transfers come from one region only, namely, OHI. The amounts are much higher than that of scenario (iv)'s. As the results, the GHG control rates on the receiving end are unrealistically high (Fig. 7). Fig. 7 implies that some regions would reduce their GHG emissions as much as 50%.

The explanations of such results are very simple. Under the utilitarian weights, regions have different shadow prices of capitals. The social planner can improve the global welfare by moving capitals from low price places to high price places. OHI is the region with the lowest shadow price of capital. However, there are no conventional capital flow channels in our setting. The capital from OHI "inundates" the small scale inter-connections of technological transfers. Such flows are redistributions under the pretext of technological transfers. Our simulation here actually explains why some other modelers' results on financial transfers are unreasonably high.

Thirdly, as a part of testing procedure, we simulate a so-called "reversal of fortune" case. Leaving the assumptions on income, mitigation costs, and climate damage as the default, we swap the donor and recipient set. In addition, the original donors (USA, OHI, and EUROPE) still exert domestic GHG mitigations. The results are predictable: Technological transfers from "poor" to "rich" are zero. Monies would not flow from low mitigation cost regions to high mitigation cost regions. This case further demonstrates that our approach for modeling or "channeling" the technological transfers is appropriate.

Fourthly, the results from scenarios (ix) and (x) prove the robustness of our approach. Fig. 8 compares the total amounts of transfers between scenarios (iv) and (ix). By adding one more donor, the transfer amounts are lower. EE's contributions to technological transfers are negligible.

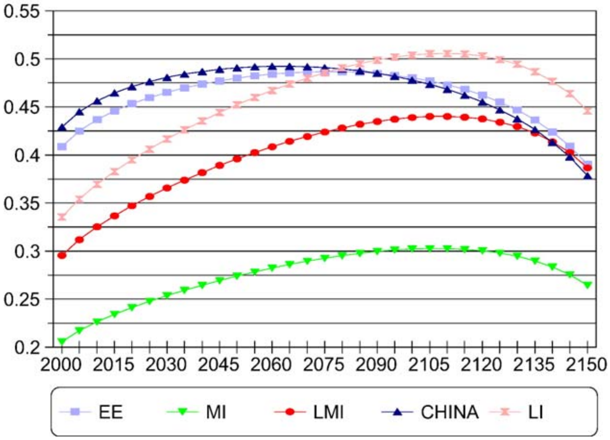

Fig. 7. GHG control rates from transfers (utilitarian weights).

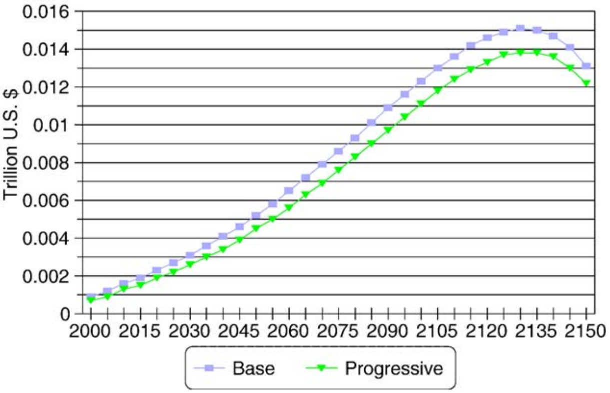

Fig. 8. Total technological transfers.

However, its absence from recipient camp shrinks the absorption capacity of transfers. The optimal transfers thus reduce. The results are consistent with intuitions. By lowering the pure time preference from 3% to 2% per year, transfers are higher. Fig. 9 compares the two cases. With lower rate of pure time preference, the donors care more about the future generations' welfare and are willing to pay more for GHG mitigations. The results are consistent with stock externality characteristics of climate change.

Finally, we compare some key outputs across the scenarios. Fig. 10 plots global GHG emissions in four scenarios: BaU, efficient outcome, quasi-"Kyoto", and quasi-"Kyoto" with technological transfers. The quasi-"Kyoto" scenario is very close to the BaU. The quasi-"Kyoto" is similar to the Kyoto Protocol only in its unilateralism but not in its stringency. It does not change the baseline GHG emissions (BaU) significantly. On the other hand, the quasi-"Kyoto" with technological transfers is very close to the efficient outcome (without transfers) under the Negishi weights. This result suggests an alternative approach to global collaboration on GHG mitigations. Promoting technological transfers, even with zero domestic efforts ($\mu_j(t)=0$) on the

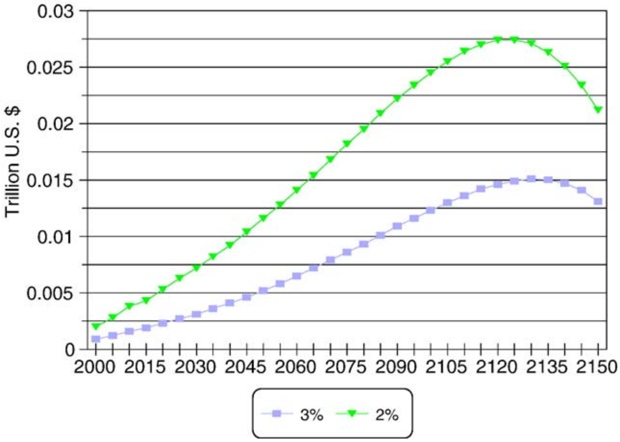

Fig. 9. Total technological transfers.

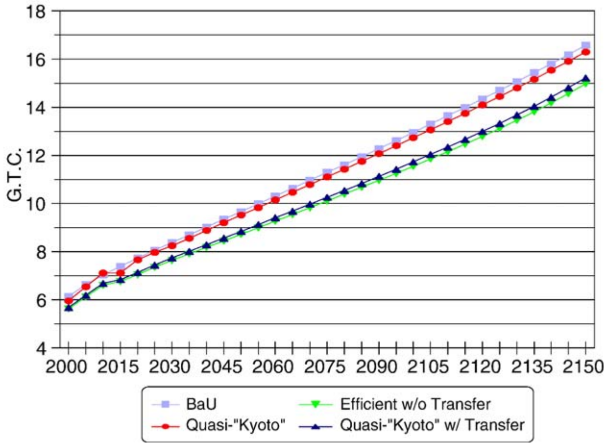

Fig. 10. Global GHG emissions.

recipients' side, can achieve similar GHG emission control targets as in the efficient cooperation scenario.

6. Conclusions

Technological transfer is an important tool for GHG mitigations. Implementing such transfers involves both technologies and policies. This paper provides a modeling approach to capture the impacts of such transfers. The method here clearly separate technological transfers from conventional financial transfers. The magnitude and directions of technological transfers from the RICE simulation are reasonable. We should point out that the simulations here do not indicate any "correct" amount of technological transfers. We only suggest a correct modeling approach to addressing technological transfer issues. When other assumptions in the model change, the technological transfers can go higher or lower.

Based on the approach in this paper, research on technological transfer issues can be expanded in several areas. Following the similar channeling mechanism, technological transfers can flow into a more detailed GHG mitigation sector. Instead of converting technological transfers to GHG control efforts which is a flow variable, the transfers can go to an environmental investment sector in the recipient region. The technological stocks from the investment contribute to GHG mitigations. Furthermore, elaborating on spillover effect and increasing return to scale of technological transfers is also a very interesting topic.

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