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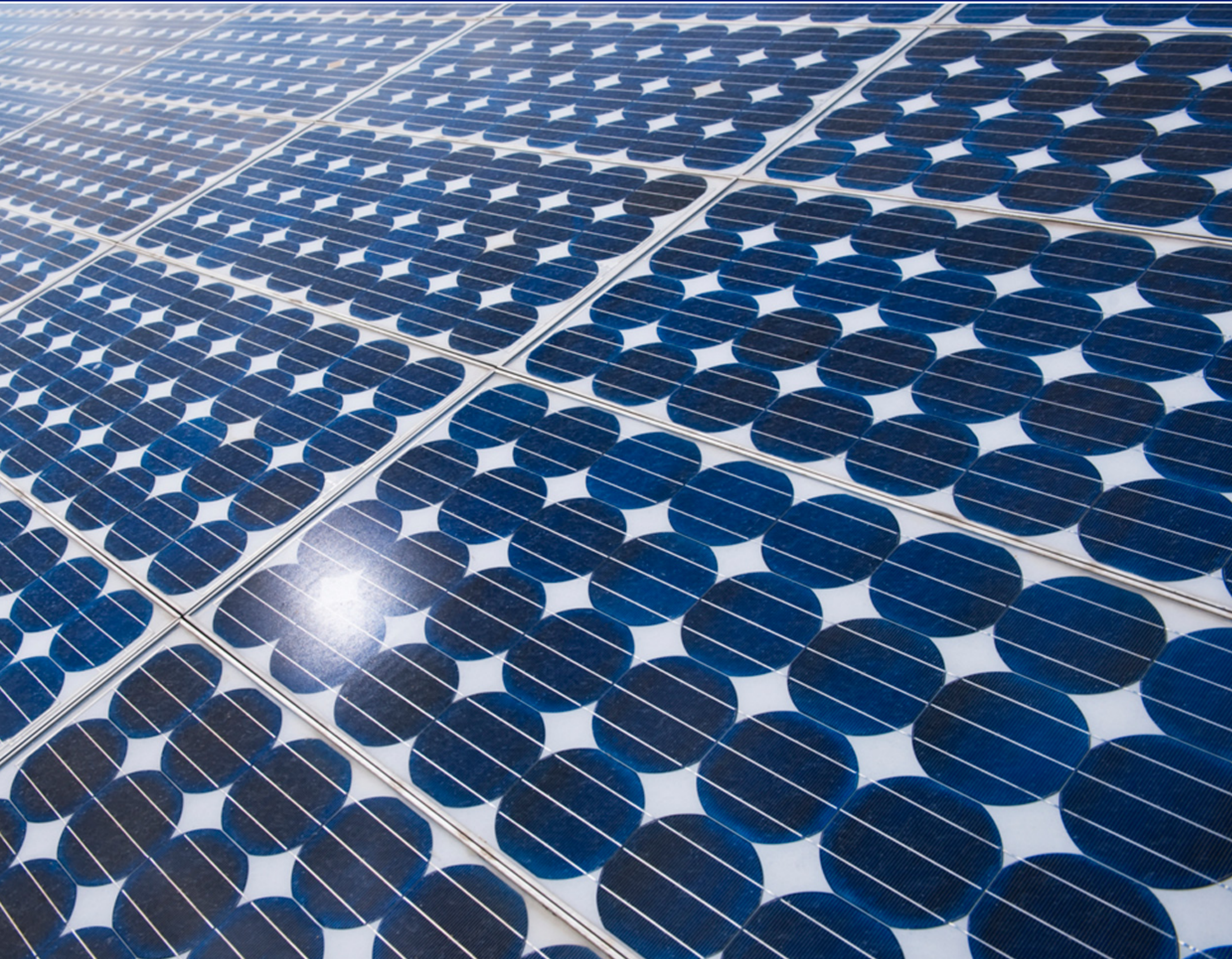
An Analysis of Technology Transfers as a Response to Climate Change

Zili Yang



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An Analysis of Technology Transfers as a Response to Climate Change

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This is an assessment report on technology transfer issues prepared for the Copenhagen Consensus on Climate Change. I thank Christian Bjornskov and David Popp for their insightful comments and suggestions on the earlier draft of this paper.

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PREFACE

ABSTRACT

Climate change poses daunting challenges to the future of humanities. Technology transfer is an effective and comprehensive approach for dealing with climate change. International cooperation on greenhouse gas mitigation and adaptation of climate change all involve in transfers of mitigation technologies or dissemination of knowledge on climate change. Technology transfer is an inseparable component of any policy response of GHG mitigation and adaptation to climate change. In this paper, we briefly define the scope of technology transfer in climate change; concisely survey the literature regarding technology transfer issues.

The central theme of this assessment paper is to provide a tentative estimation of benefit and cost ratio (B/C ratio) of technology transfers in climate change. Technology transfer is an encompassing notion in climate change policies because mitigation and adaptation all requires technologies. Quantifying B/C ratio of technology transfer is extremely difficult due to diversity of technologies and different institutional setting of transfers. In this paper, we adopt an indirect approach to estimate B/C ratio of technology transfer. Namely, we capture the financial transfer flows - the dual part of technology transfer flows. Using the RICE model, the optimal financial transfers that facilitate technology transfers are calculated under two representative policy scenarios and two different discount rates. The B/C ratios are estimated from the model solutions.

Major findings include: magnitudes of technology transfers are policy-related and vary significantly in different policy scenario; enabling technology transfers always have net gains thus are desirable; assessing the benefits and costs of technology transfers have to be in connection with the underlining policies; promoting tangible and intangible technology transfers is crucial for dealing with climate change.

COPENHAGEN CONSENSUS ON CLIMATE

The Copenhagen Consensus Center has commissioned 21 papers to examine the costs and benefits of different solutions to global warming. The project's goal is to answer the question:

"If the global community wants to spend up to, say $250 billion per year over the next 10 years to diminish the adverse effects of climate changes, and to do most good for the world, which solutions would yield the greatest net benefits?"

The series of papers is divided into Assessment Papers and Perspective Papers. Each Assessment Paper outlines the costs and benefits of one way to respond to global warming. Each Perspective Paper reviews the assumptions and analyses made within an Assessment Paper.

It is hoped that, as a body of work, this research will provide a foundation for an informed debate about the best way to respond to this threat.

CONTENTS

INTRODUCTION

Climate change is a persevering challenge faced by entire humanities in the 21st century and beyond. Economic activities since the industrial revolution, mainly fossil fuel combustions and agriculture, have emitted huge amounts of greenhouse gases (GHGs) into the atmosphere. The anthropogenic GHG emission is the main source for measureable atmospheric temperature increases over the past decades (IPCC, 2007). Economists predict that global GHG emissions will keep increasing in the future, which will lead to further temperature increase. The climate that human beings have been used to for centuries will change drastically (IPCC, 2007).

The detrimental impacts of climate change have long-lasting, sometimes irreversible, consequences. To alleviate these impacts, international cooperation on GHG emission reduction is urgently called for. The United Nations framework Convention on Climate Change (UNFCCC), established in 1992, has been the grand institutional setting for potential international cooperation on climate change. Technology transfers as the means of international cooperation and concrete approach of GHG mitigation have been at the center of policy debates and on the negotiation table.

International community has recognized the vital importance of technology transfer in coping with climate change. Without technology transfers, "it may be difficult to achieve emission reduction at a significant scale." (IPCC, 2007) Technology transfer should be a key component of any effective GHG mitigation strategies. Therefore, comprehensive studies of technology transfer issues are crucial to GHG mitigation policy designs and implementations.

In this assessment paper, I survey the scope of issues surrounding technology transfers in the context of climate change and conduct some rudimental cost benefit analysis on a few options of technology transfers. The remaining parts of the paper are organized as follows: Section 2 contains general discussions and surveys on technology transfers; Section 3 is the cost benefit analysis of transfer issues under different assumptions and policy backgrounds; Section 4 contains some concluding thoughts.

DESCRIBING TECHNOLOGY TRANSFERS

Technology transfer (TT) is an encompassing theme in policy discussions of climate change. In the text of UNFCCC, "transfer of technologies" is identified as the means for mitigating GHG emissions and adapting the impacts of climate change (UNFCCC, Articles 4, 9, and 11). In subsequent 14 sessions of Conference of Parties (COP), decisions made on "development and technology transfer" appeared 12 times (all but COP – 6 and COP – 9). The Clean Development Mechanism (CDM), an important channel for potential transfers of GHG mitigation technologies, is the treaty contents of the Kyoto Protocol (Article 14). Since the inception of IPCC in 1988, technology transfer has been a perpetual theme on its agenda. All 4 assessment reports of IPCC (IPCC, 1992, 1996, 2001, 2007) contain detailed analysis of TT issues. In 2000, IPCC published a special report on technology transfer, titled ***Methodological and Technological Issues in Technology*** Transfer (IPCC, 2000a). This volume of over 400 pages, collaborated by over 200 contributors, is the most comprehensive study on TT in the context of climate change.

Transfer of environmentally sound technologies (EST) from developed countries to developing countries plays a key role in mitigation and adaptation in climate change; technology diffusions among developed countries also enhance the effectiveness of GHG mitigation efforts. COP documents and IPCC reports demonstrate the vital importance of technology transfers in dealing with climate change.

2.1. The Definition of Technology Transfers

The concept of technology transfer can be very broad. Here we quote the definition of technology transfer from IPCC (2000a): "[technology transfer is] a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, NGOs and research/education institutions". Nevertheless, TT may convey varied connotations by scholars or decision makers under different contexts. The above definition is a balanced one.

The description of TT concept contains several components. In TT processes, there are providers/donors and recipients. Providers/donors are generally from developed countries; recipients are in developing countries. A TT process takes place across borders. The entities (stakeholders) in a TT process can be governments, NGOs, international agencies, or private sectors. In this assessment paper, we use developed countries (North) and developing countries (South) as "proxies" for entities in TT processes.

TT processes involve primary flows and dual flows. The primary flow is tangible technologies or intangible "know-how" from developed countries to developing countries; the dual flow is the money that finances the TT. While the sources and destinations of the primary flows are transparent (from North to South), the directions of the dual flows can be complicated. If developed countries fund the TT process, money flows from North to South; if the TT process is a part of international trade transaction, money flows from South to North.

The institutional setting and market structure of TT processes are diverse. Both governments and international organizations sponsor and channel TT. Some exemplary projects of TT have governmental backings on both sides. For example, many EST projects have been launched under the auspice of OECD/IEA (Philibert, 2004); sizeable TT projects are under way under the framework of CDM (de Connick etc., 2007). In these circumstances, North is properly called "donor." Nevertheless, many TT activities are mixed in commercial trades or are parts of foreign direct investments (FDI) (Less and McMillan, 2005). In such setting, technology is sold to developing countries by developed countries. Thus North is a "provider" (of technology) not a "donor."

The implementation of TT includes a litany of possible projects and measures in many sectors in developing countries. The tangible TTs take place in energy supply, transportation, agriculture, and many other industries; the intangible TTs are spreads of knowledge on more effective energy usage, protecting the global environment, etc. The intangible TTs permeate from North to South through education and exchange of ideas.

2.2. Transfer Issues in the Literature

Over the past decade, studies of transfer issues in the context of climate change have been extensive. Hundreds, if not thousands, of scholarly papers, reports, and documents have been devoted to TT in climate change. The literature on transfers can be categorized in four strands:

i. The publications by IPCC. Discussions of TT in ARs (IPCC, 1996, 2001, 2007) and Special Report on TT (IPCC, 2000a) represent collective understanding of TT in climate change by international communities. They also offer policy guidelines for implementing TT projects. Particularly, IPCC (2000a) is a rich source of TT literature. Its bibliographies in chapters include hundreds of articles and documents on all aspects of TT issues.

ii. Independent studies of TT issues in the context of climate change. Many peer-reviewed articles as well as reports assess TT issues outlined in UNFCCC and the Kyoto Protocol. For example, Ellis et al. (2004) reviewed the progress and outlook of CDM; Brewer (2008) examined the institutional and legal aspects of TT issues; Saggi (2004) surveyed the relationship between trade, FDI, and TT; Martinot et al. (1997) engaged in country studies of TT in climate change. The literature on broad issues related to technologies is a huge reservoir. Comprehensive survey requires extensive volumes.

iii. Transfer issues in international environmental agreement (IEA) studies. Climate change stimulates the studies of IEA by game theorists and environmental economists. Transfers in IEA studies, an abstract monetary transfer that is broader than TT as defined in UPCC (2000a), are widely adopted to ensure the formation of IEA. In numerical simulations of IEA models, the transfer amounts are quantified. In this line of the literature, timing and intensity of transfers are not in consideration. The amounts and directions of transfers sometimes are questionable from policy perspective.[1]

iv. Transfer issues in integrated assessment modeling (IAM) of climate change.[2] In most IAMs, various financial transfer mechanisms are introduced to calculate "efficient" GHG mitigation policies. Economic theories state that a global GHG mitigation policy is efficient when marginal costs (MC) of GHG mitigation are equalized across regions. Such MC equalization requires financial transfers. The interpretation of material flow counterpart of such transfers is TT. The transfer amounts and directions in IA models are much more reasonable than those in (iii). Nevertheless, the speed of TT or "absorptive capacity" of recipients is not considered in these models. Such restrictions always exist in real economies (Borensztein et al., 1998).

2.3. Technology Transfers in Practice

The history of TT is as long as that of international trade. TTs targeted at coping with climate change have grown in the past decade. Many TTs project between developed and developing countries are in negotiation processes. IPCC (2000a) includes 30 case studies of TT in GHG mitigation and adaptation of climate change. The diversity of these projects shows promising potentials of TT in

1 The literature in this field is abundant. Because they are not connected to the issues in this assessment paper, we do not survey them here.

2 For comprehensive descriptions of major IAMs, see Energy Modeling Forum 22 at http://emf.stanford.edu

the future international cooperation on climate change. Nevertheless, the scopes and magnitudes of TT projects thus far fall short of demanding tasks of global GHG mitigation.

COST BENEFIT ANALYSIS OF TT UNDER DIFFERENT ASSUMPTIONS AND POLICY BACKGROUNDS

3.1 Backgrounds and assumptions

TT is an important and all-inclusive option for GHG mitigation and adaptation of climate change. All perceivable international cooperation on climate change is necessarily implemented through TT directly or indirectly. Cost-effective GHG mitigation policies require that mitigation costs are equal at margin for all regions. When developed countries helping developing countries in their GHG mitigation efforts with money, TTs are behind such financial transfers. Regardless of institutional setting, such as CDM, JI, or FDI at private sectors, TTs are material counterparts of financial transfers from North to South.

Due to the “all-inclusive” characteristics of TT issues, TT as a “solution” option for climate change always encompasses with other “solutions” in this assessment paper series. If GHG mitigation and adaption measures takes place domestically (traditional or alternative), the TT does not occur; if GHG mitigation in developing countries is supported with technologies from developed countries, TT is in play. In latter case, TT offers incremental benefits to solving climate change. In figurative terms, we try to quantify the cost and benefit of the second T in TT while treating the first T as a pre-condition. However, it is difficult to credit a share of potential gains of trans-boundary mitigation activities to TT or to mitigation itself. Conventional cost-benefit analysis approach is not valid here.

It is widely recognized that the scope and costs of TTs are very difficult to quantify, as concluded in IPCC SR (2000a) that “little is known about how much climate-relevant hardware is successfully ‘transferred’ annually.” Cost estimates on individual TT projects are hard to aggregate into regional or global levels. Intangible TTs, such as capacity building and education, are not quantifiable monetarily, especially for their potential benefits in long-run. In addition, the future of technological progresses often turns out to be unpredictable. Therefore, cost benefit analysis of TT as a “solution” for climate change cannot base on a plethora of project evaluations. In other words, direct engineering approach is not feasible for such assessment. We must adopt an indirect economic approach.

The tentative analysis provided in this assessment paper is established on the “dual” side of material flows of TT. Namely, we follow the financial transfers associated with TT. In the literature, financial flows are accepted as “proxies” for TT with qualifications (IPCC, 2000a). In IPCC (2000a), “financial resource flows” are used to track historical trends and patterns of TT in climate change. In fact, any financial flows in the context of climate change necessarily have material flow counterparts. Such material flows are TTs defined in the previous section. However, there are caveats in this approach. To make the analysis more credible and to avoid misunderstanding, the assumptions for the analysis framework need to be elaborated.

i. Intangible TTs are not included in the analysis. From cost benefit analysis point of view, the costs of spreading "know-how" are very low but the "intangible" benefits are huge. For the reasons stated previously, such benefits are difficult to quantify. Furthermore, the impacts of intangible TTs do not transpire directly or immediately into GHG mitigation measures. Having said so, the potential contribution of intangible TT to GHG mitigation and adaptation to climate change can be tremendous in the long run, as the impacts of technology spillovers on other dimensions of societies (Keller, 2004).

ii. Financial transfers are efficient. The assumption implies that a unit of financial transfer is backed by TT at competitive market price. In addition, TTs are applied to the most cost-effective sectors for GHG mitigation or adaptation of climate change in developing countries. Thus, the financial transfers represent the efficient allocations of mitigation technologies worldwide. Admittedly, such "low-hanging fruits" principle may not be the case in real life. For example, EU and China are negotiating on transferring advanced carbon sequestration technologies now despite large portion of Chinese energy supplies continue using out-of-date inefficient technologies.

iii. Broad interpretation of financial transfers follows category (iv), not category (iii), in the literature reviews. In IEA studies, transfers are used as tools to facilitate the formation of coalition. Institutional reality and practicality of transfers are not considered in these types of models. In the numerical simulations of coalition models, the transfer values at billion even trillion dollars can flow into any regions on annual basis. On the other hand, IA models are more attentive to data calibration and are policy oriented. Forecasting scenarios and policy solutions in IAMs are based on the best knowledge of the modelers and consensus among the peers. In these IA models, transfer channels are set up in such way that sole purpose of its presence is to ensure cost-effective GHG mitigation globally. The magnitude and directions of transfers are much more realistic in IAMs. Consequently, transfers in IAMs are the best reflection of TTs. Nevertheless, the "absorptive capacity" is not considered in most models.

iv. Optimal TTs are policy dependent or policy-driven. Different GHG mitigation policy scenarios require different transfer regimes. Particularly, when regions fulfill their international GHG mitigation obligations, such as set by the Kyoto Protocol, they may offer transfers (developed countries) or receive transfers (developing countries) to achieve their mitigation targets collectively. Transfer amounts and directions are determined by policy targets. Assessing GHG mitigation policies, TT is a part of larger picture and seldom a whole picture. For example, many pilot projects under CDM framework of the Kyoto Protocol are parts of donors' and recipients' cooperation on GHG mitigation. One cannot say that CDM projects represent the entirety of donors or recipients GHG mitigation policy.

3.2. Methodologies

As mentioned above, the cost benefit analysis here targets at "transfer", not "technology." There are at least three measurements of B/C ratios of TT. The first is defined as follows: the costs are measured at total mitigation cost under the TT scheme; the benefits are measured as total mitigation cost reduction without the transfers. Here B is avoided high mitigation costs and C is actually incurred mitigation costs.

Optimal TTs always have net gains, otherwise they do not happen. Based on these observations, the second measurement of B/C ratios of TT is follows: the cost is measured at total financial transfer amount T; the benefit is the net gains in mitigation cost reductions from the TT scheme. Namely, B/C ratio is defined as: $(B_1\text{-}C_1)/T$. Here B_1 and C_1 are benefit and cost calculated in the first measurement. In this assessment paper, we present both measurements.

The third measurement is broader, but probably vague. We use reduced climate damage (compared with business as usual (BaU) scenario) in policy scenario with TT as the benefit of TT; transfer amounts incurred in the policy as the cost. Here B/C ratio is defined as $\Delta D/T$.

Because TT is associated with GHG mitigation activities and particular policies, separating cost and benefit of TT from mitigation itself can be tricky. TT should not take credit for the total benefit of whole mitigation efforts. The contribution of TT may be large, may be small. For example, in two mitigation policy scenarios involving TT, the inferior one with lower overall B/C ratio might have higher B/C ratio from TT. In a simple arithmetic expression: when $B_{t,1} > B_{t,2}$, it does not imply that $B_1/C_1 > B_2/C_2$ (here $B_{t,1}$ and $B_{t,2}$ are benefits from TT in policy #1 and #2; B_1, C_1 and B_2, C_2 are total benefits and costs of policy #1 and #2 respectively).

We use the following hypothetical example to illustrate first two B/C measurements. Suppose achieving certain mitigation target incurs 10 million dollars of cost globally without TT. A TT scheme with 1 million dollars transfers combining with domestic mitigation efforts reduces the global mitigation cost to 8 million dollars. The benefit (avoided high costs) B = 10 million dollars; the cost (actually incurred) C = 8 million dollars; B/C ratio is: B/C = 10/8 = 1.25 in the first measurement. The net gains from TT here are (10-8) = 2 million dollars. The second measurement of B/C ratio is $(B_1\text{-}C_1) / T = (10\text{-}8)/1 = 2$.

There are different approaches to assess a project or policy in cost benefit analysis (Layard, 1994). It is difficult to claim that one B/C ratio measurement is always superior to another, at least in the case here. The three B/C ratio measurements cover different aspects of TT. The complementary nature renders them both useful.

Using the above mentioned three measurements of B/C ratios, this paper conducts cost benefit analysis of TT in the RICE model developed by Nordhaus and Yang (1996). Estimation methodologies are heavily relied on Yang (1999), Yang and Nordhaus (2006), and Yang (2008). The RICE model is a multi-region extension of aggregate DICE model (Nordhaus, 1994, 2008). Regional breakdown of RICE is essential for modeling TT issues because transfers flow across borders.

To set up the model for dealing with TT issues, financial transfers are introduced in the RICE in such ways that the transfer costs of donors (developed countries) are deducted from their GDP, the transfers go into the GHG mitigation functions of recipients (developing countries). The purpose of transfer is to mitigate GHG emissions more cheaply in recipient countries. The donors benefit from the transfer through reduced climate change impacts. Such model structure rules out the effects of pure welfare transfers that monies go directly into developing countries' treasury and nothing happen to GHG mitigation.[3] The modeling methodology is proper for connecting financial transfer to TT. Finally, the transfer amounts are endogenous. The model solution reflects the optimal transfers under a given policy scenario.

For this assessment paper, two policy scenarios (solution categories) are proposed for cost benefit analysis of TT. The first is the Kyoto Protocol like scenario that lasts for the entire modeling horizon. In this case, developing countries do not obligate to reduce their baseline GHG emissions. They will mitigate GHG emissions, if developed countries pay them to do so through CDM, JI, or FDI. On the technology part, all mitigation efforts in South use the technologies provided by North. North takes credits for the outcome. The final outcome of such TT scheme is equalization of marginal costs of GHG mitigation across all regions. Using the "fruit" metaphor, all "fruits", low hanging or high hanging, in Southern orchard, are picked with North technologies and financed with Northern money. The harvesting activities in Southern orchard will go on until all untouched fruits hang at the same height as the remaining fruits in Northern orchard.

In the second scenario, developing countries shoulder certain GHG mitigation obligations that are compatible with their own incentives (considering climate change impacts on them).[4] After developing countries fulfill their mitigation obligations, developed countries will help developing countries on further GHG mitigation, through TT, to achieve a globally cost-effective GHG mitigation outcome. A scenario of international cooperation on GHG mitigation like this has been a target sought by some developed countries in post-Kyoto negotiations. Particularly, GHG mitigation commitment by major developing countries, such as China, India, and Brazil, is probably the focal agenda in the coming Copenhagen COP-15. In this scenario, developing countries with their indigenous technologies will exploit the "low hanging fruits" mitigation opportunities. For example, it is not necessary to use advanced technology from Europe to replace all old coal burning technologies in China. Equipments with mature technologies and manufactured in China can improve the fuel efficiency sufficiently.

In calculation of TTs in the above two scenarios, how much the global community wants to spend on TT is based on the optimal solution of the model under the given policy scenario, not prescribed. We cannot phrase the TT issue by treating the amount of TT as exogenous, such as "what is the cost and benefit of spending 1 billion dollars on TT in a year." Our calculations of B/C ratios are ex-post or side calculations after policy driven TTs, along with other control and state variables, are solved endogenously.

Many other TT scenarios in parallels can be proposed. The above two probably locate on the polar ends of potential roles of TT. Due to volume limitation of this paper, technical aspects of modeling are not fully explained here. Readers can find the detailed modeling methodologies in RICE that are related to the scenarios here in the papers and the book cited above.

3 In most IAMs, the distributional (wealth) effects of transfers are not separated from GHG mitigation cost reduction effects. Therefore, financial transfers in these models probably are over-estimate optimal TT volumes.

4 More specifically, the policy scheme is close to the Lindahl equilibrium outcome in Yang (2008). Each region's initial mitigation obligation is based on respective 'willingness to pay" principle.

3.3. Calculation results of cost benefit analysis

The time frame of the calculation follows the guideline set for assessment papers. The costs and benefits are expressed as the present values of flows of costs and benefits for 100 years (2005- 2105) at given discount rate (r = 3% and r =5%). In addition, the current values of these flows are also calculated. TTs, costs and benefits associated with them are flows over time. Policy scenarios may affect the timing and volume of TT. Therefore, current value (CV) is a useful piece of information.

We summarize the simulation scenarios as follows:

i. Scenario 1: Kyoto Protocol like case at r = 3% and 5%. In this case, global GHG mitigation outcome is stringent. Much of initial GHG mitigation burdens are on developed countries.

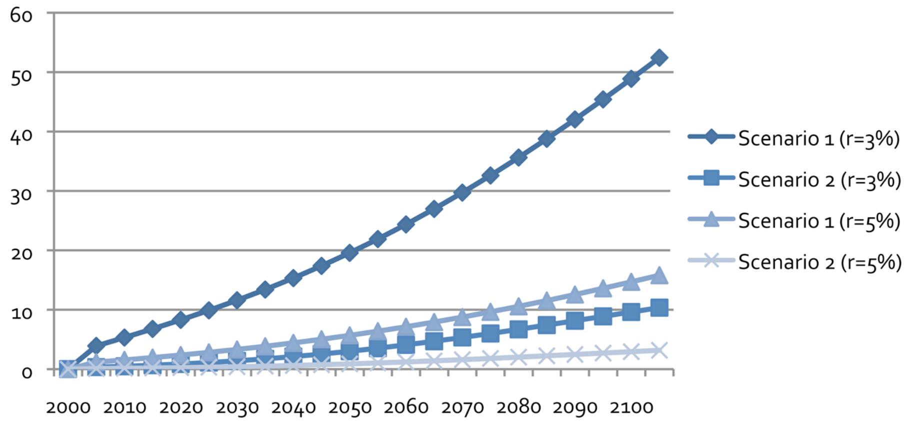
ii. Scenario 2: A full-cooperation case based on willingness to pay principle at r = 3% and 5%. In this case, global GHG mitigation outcome is less stringent, compared with scenario 1. All regions obligate to GHG mitigation based on their mitigation costs and climate damage situations.

The numerical calculations are based on a six-region version RICE model used in Yang (2008). In this version, three regions (USA, European Union, and other high-income countries (OHI)) are donors/providers in TT schemes; the remaining three regions (China (CHI), Former Soviet Union and Eastern European countries (EEC), and the rest of the world (ROW)) are recipients. The model's baseline GHG emission prediction is in the mid-range of IPCC SRES (IPCC, 2000b). The optimal solutions in Yang (2008) are moderate, comparing with other IAMs.

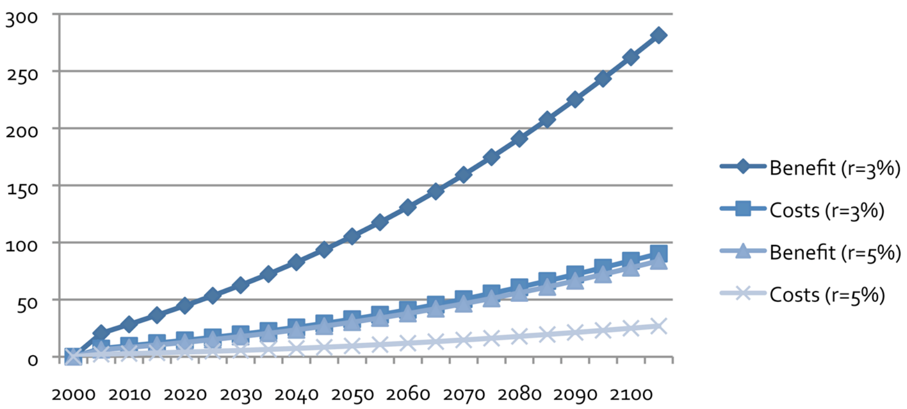
The results of cost benefit analysis of TT are presented in the following three overview tables. The calculations procedure is outlined as follows: first, the optimal solutions without transfers in different scenarios are obtained. This step is as if each region is picking the "low hanging fruits" in GHG mitigation opportunities within the borders, according to their obligations specified by the policy. In the solutions, North always reaches higher "fruits." It implies that North incurs higher mitigation costs than South. Second, the necessary (minimum) amounts of transfers that enable the equalization of marginal mitigation costs are obtained through a set of side-calculations. The outcome reflects that North explores "low hanging fruits" opportunities in South through TT, "returns" some "high hanging fruits" in North, and the total numbers of harvested "fruits" remains the same globally before and after TT. Third, addition calculations are conducted to obtain cost and benefit values according to the definitions discussed in section 3.2.

Other relevant results are presented in the following graphs: Graph 1 contains the optimal transfer flows over time in different scenarios; graph 2 depicts benefit and costs flows, as defined in the first measurement, in Scenario 1; graph3 is the same flows as in graph 2 for Scenario 2. Graphs 2 and 3 capture the shift of mitigation flows caused by TT.

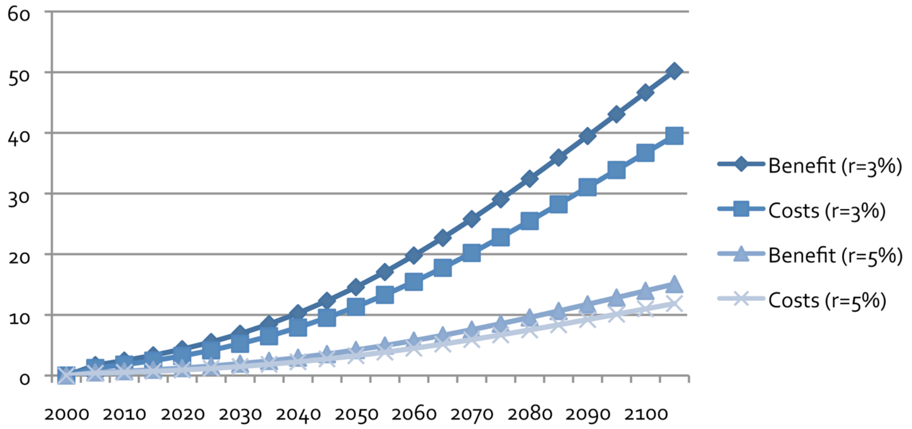
Graph 1. Optimal Transfer Amounts (Billion 2000US$)



Graph 2 Flows of Benefit and Costs (Scenario 1)



Graph 3 Flows of Benefit and Costs (Scenario 2)



Overview Table 1 Present Value of Total Global Benefits and Costs of TT in 100 Years (the First Measurement) (unit: billion 2000 US$)

Scenario 1								
Benefit and Costs	r = 3% Benefit	Costs	CV Benefit	Cost	r = 5% Benefit	Costs	CV Benefit	Cost
	2523	805	13688	4355	347	112	4000	1272
B/C Ratios	3.134		3.143		3.098		3.144	
Scenario 2								
Benefit and Costs	r = 3% Benefit	Costs	CV Benefit	Cost	r = 5% Benefit	Costs	CV Benefit	Cost
	339	262	2160	1688	42	32	637	498
B/C Ratios	1.294		1.280		1.312		1.279	

Overview Table 2 Present Value of Total Global Benefits and Costs of TT in 100 Years (the Second Measurement) (unit: billion 2000 US$)

Scenario 1								
Benefit and Costs	r = 3% Benefit	Costs	CV Benefit	Cost	r = 5% Benefit	Costs	CV Benefit	Cost
	1718	470	9333	2551	236	66	2728	754
B/C Ratios	3.655		3.659		3.576		3.618	
Scenario 2								
Benefit and Costs	r = 3% Benefit	Costs	CV Benefit	Cost	r = 5% Benefit	Costs	CV Benefit	Cost
	77	70	472	445	10	8.5	139	134
B/C Ratios	1.10		1.061		1.17		1.037	

Overview Table 3 Present Value of Total Global Benefits and Costs of TT in 100 Years (the Third Measurement) (unit: billion 2000 US$)

Scenario 1				
Benefit and Costs	r = 3% Benefit	Costs	r = 5% Benefit	Costs
	1221	470	190	66
B/C Ratios	2.60		2.88	
Scenario 2				
Benefit and Costs	r = 3% Benefit	Costs	r = 5% Benefit	Costs
	746	70	112	8.5
B/C Ratios	10.66		13.18	

The above tables and graphs outline the general overviews of TT as reflected by the RICE model. In scenario 1, both the magnitude of and potential gains from TT are huge. Valued with both cost/benefit measurements, B/C ratios are greater than 3 in Scenario 1. In this case, developed countries have to rely on TT to reduce the costs of their GHG mitigation burdens. Here, TT plays the most important role in reducing global GHG mitigation costs. Most GHG mitigation activities in developing countries are financed by developed countries and use imported technologies. Given the burden sharing rule like this, one would wonder why developed countries agree to such arrangement in the first place. TT reduces mitigation costs of developed countries; TT attracts developing countries joining in the global cooperation in GHG mitigation. However, the initial policy setting is not the most desirable one for some regions.

Scenario 2 represents the case in which all "low hanging fruits" of GHG mitigation options in developing countries are exploited domestically with indigenous technologies. Such voluntary actions are based on common concerns about climate change by all regions. Maximum participation by developing countries has been pushed very hard by some developed countries, such as the United States, in post-Kyoto negotiations. On top of domestic efforts with indigenous technologies in developing countries, advanced TTs take place to equalize MC of mitigation costs across all regions after all cheap options are exhausted domestically. In Scenario 2, both the magnitude of and the gains from TT are much lower than they are in Scenario 1. B/C ratios under two measurements are slightly higher than 1. Such result shows that marginal gains from "picking high hanging fruits" are small. The result in this scenario does not imply that technology has little to do with GHG mitigation. It indicates a scenario in which transfer amounts could be moderate. Domestic GHG mitigations need technologies.

The three measurements are basically consistent with one another. They all show that implementing TT create a win-win outcome for both donors/providers and recipients when compared with no TT results. Here we should also indicate that climate damages are predicted to be more severe beyond the 100 year time span for this assessment work. Mitigation efforts in this century, in part, are aimed at reducing climate damage beyond 100 years. Cost benefit measurement truncated in time may under-estimate true benefits, compared with longer time horizon calculation. This caution is applicable for the third measurement.

The two scenarios reflect two extreme situations involving TT. The calculated transfer amounts are the minimal/optimal transfers that equalize the marginal mitigation costs globally. Net of values of intangible TT, the estimated total costs and benefits of TT and transfer amounts in Scenario 1 should be on the upper bound of the potential scope of TT in the next century; those in Scenario 2 should be on the very low bottom of the potential scope of TT in the next century. The actual outcomes of TT are probably somewhere in the middle of the two scenarios. If the values of intangible TT could be included in the estimation, the net benefits of TT in the long run would be much higher.

Finally, all TTs are motivated by specific mitigation policies or international negotiation outcomes. We cannot draw any conclusions on the policies or infer B/C ratios of those policies based on cost benefit analysis of TT alone. In this assessment paper, we do not claim that policies behind Scenario 1 are superior to those in Scenario 2 because the gains from TT are larger. As we emphasized repeatedly, the evaluation of TT has to be in connection with other parts of mitigation and/or adaptation processes. For any GHG mitigation policy, incorporating TT can reduce the aggregate costs further. Therefore, TT is ubiquitous in optimal GHG mitigation policies.

CONCLUSIONS

TT, in conjunction with other "solution categories" in this series, is an effective option of GHG mitigation and adaptation of climate change. Despite that it is never a stand- alone solution, TT is a part of all meaningful GHG mitigation policies from global perspective. Technology progress is the key for the challenges human beings will be facing in the future. Climate change is one of such challenges. Since climate change is a global phenomenon, international cooperation that involves all nations is necessary for cost-effective GHG mitigations. TT is combination of technology and international cooperation. Therefore, it is an inseparable component of any climate change policies.

In this assessment paper, we conduct the cost benefit analysis of TT in the context of climate change. Cost and benefit analysis of TT at global level and in the long run, is very difficult. Unlike the project evaluation of individual CDM undertaking where costs and benefit (to lesser degree) are measurable, aggregate effects of TT are not simple additions of individual projects. We hope that the indirect methods used here can shed some lights on evaluation of effectiveness of TT in dealing with climate change.

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