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A Perspective Paper on Technology Transfers as a Response to Climate Change

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David Popp

Center for Policy Research, The Maxwell School, Syracuse University, 426 Eggers Hall, Syracuse, NY 13244-1020
and
National Bureau of Economic Research, Cambridge, MA 02138

dcpopp@maxwell.syr.edu

Copenhagen Consensus Center
Copenhagen Business School
Solbjerg Plads 3
DK-2000 Frederiksberg
Denmark

+45 3815 2255
info.ccc@cbs.dk
www.copenhagenconsensus.com

ABSTRACT

While developed countries begin to constrain growth in carbon emissions, emissions from developing countries are growing. Nonetheless, given that most historical emissions came from high-income countries, and that low-income countries desire increased economic growth, developing countries currently do not face binding emission constraints. However, alternative policy options, such as the Clean Development Mechanism, provide a means for encouraging emission reductions in developing countries via technology transfer. Yang's assessment paper provides an estimate of the potential of technology transfer as a climate policy option. This paper provides a critique of that assessment. Yang focuses on the direct gains from developed country financing of abatement in developing countries - namely, the opportunity to replace high marginal cost activities in the developed world with low marginal cost activities from the developing world. However, Yang omits an important secondary gain from technology transfer - the potential for knowledge spillovers. This paper assesses the potential role that spillovers might play, and offers an assessment of the overall potential of international technology transfer as a policy solution. While important, international technology transfer cannot stand alone, but rather must be part of a menu of policy options.

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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.

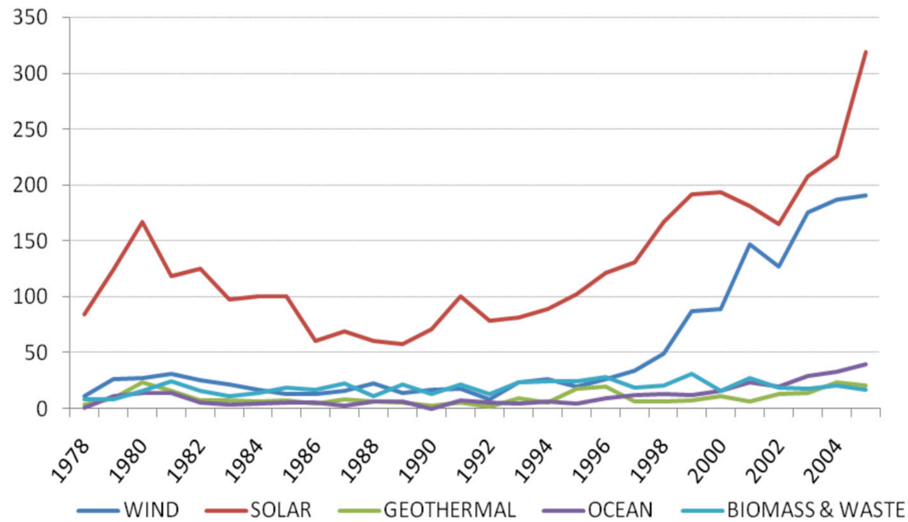
CONTENTS

1. INTRODUCTION

Reducing carbon emissions without dramatic reductions in output and consumption requires the use of new technologies. These may be as simple as improvements in energy efficiency, or involved advanced technologies for generating electricity from solar power or capturing and storing carbon emissions from coal combustion. Recent efforts to reduce emissions in developed countries stimulated the development of many such technologies, as illustrated in Figure 1. This figure shows dramatic increases in increases in inventive activity for renewable energy technologies, measured by applications for renewable energy patents submitted to the European Patent Office (EPO), corresponding to both national policies and international efforts to combat climate change that followed signing of the Kyoto Protocol in December 1997 (Johnstone *et al*., forthcoming). Similarly, increased energy prices that accompany a carbon tax or emissions trading scheme have led to innovation in both energy efficiency and alternative energy sources (Popp, 2002).

As is the case with most R&D, this increased innovation has occurred primarily in the developed world (Dechezleprêtre, Glachant, Hascic *et al*. 2008).[1] At the same time, carbon emissions from developing countries have become a greater concern. For instance, in 1990, China and India accounted for 13 percent of world carbon dioxide (CO_2) emissions. By 2004, that figure had risen to 22 percent, and it is projected to rise to 31 percent by 2030. Overall, the U.S. Energy Information Administration projects that CO_2 emissions from non-OECD countries will exceed emissions from OECD countries by 57 percent in the year 2030 (Energy Information Administration, 2007).

Figure 1 – Number of EPO Patent Applications for Renewables by Type of Technology



Source: Johnstone *et al*. (forthcoming)

The figure shows the number of European Patent Office (EPO) applications for patents pertaining to various renewable energy technologies, sorted by the year of application.

1 In 2006, global R&D expenditures were about $960 billion, with 85 percent of this R&D occurring in the OECD, and half in the United States and Japan alone (OECD 2008).

Due to the growth in emissions from developing countries, designing policy that encourages the transfer of clean technologies to developing countries has been a major discussion point in climate negotiations. Currently, the Kyoto agreement includes the Clean Development Mechanism (CDM), which allows polluters in industrialized countries with emission constraints to receive credit for financing projects that reduce emissions in developing countries, which do not face emission constraints under the Kyoto Protocol. Because carbon emissions are a global public good, CDM can help developed countries reach emission targets at a lower total cost, by allowing developed country firms to substitute cheaper emissions reductions in developing countries for more expensive reductions in the home country. For developing countries, technology transfer and diffusion of clean technologies may be an additional benefit from CDM.[2]

Technology transfer provides several potential benefits. By providing access to technologies not readily available in developing countries, technology transfer can take advantage of unused, low-cost emission reduction opportunities in developing countries. Taking advantage of these opportunities results in a lower total cost of emissions reductions, by allowing substitution from high marginal cost activities in developed countries to low marginal cost opportunities in developing countries. It is these cost-saving benefits that Yang captures in his simulation.

Perhaps more important, however, are the potential dynamic gains that come from technology transfer. By increasing the technology base of the recipient country, transfers of climate-friendly technology potentially lower the marginal abatement cost curve of the recipient country, making future emissions possible at lower costs. When considering environmental policy, countries weigh the benefits of a cleaner environment against the costs of complying with the regulation. Technological advances lower the cost of compliance, making regulation more likely. For instance, Lovely and Popp (2008) show that access to better pollution control technologies results in countries adopting environmental regulation at lower levels of per capita income over time. Exemplifying this, China's 2006 Report on the State of the Environment in China declared scientific innovation the key to "historic transformation of environmental protection" and "leap-frog development". By lowering future carbon mitigation costs, technology transfer can provide important dynamic benefits by increasing the willingness of developing countries to commit to binding carbon emission reductions.

2. CHALLENGES TO MODELING TECHNOLOGY TRANSFER

Modeling the costs and benefits of international technology transfer has many challenges. First, technology transfer does not occur in a vacuum. Because carbon emissions are not priced in free markets, there is little incentive to reduce emissions in the absence of climate policies that reduce emissions, either through restrictions on emission levels or tax policies that place a price on carbon emissions.[3] This holds true for technology transfer as well. With the exception of some energy efficiency technologies, clean technologies typically do not flow across borders unless environmental policies in the recipient country provide incentives to

2 Lecocq and Ambrosi (2007) provide a description of the Clean Development Mechanism. Popp (2008) discusses the potential for technology transfer via CDM.

3 Note that some actions that reduce emissions, such as improving energy efficiency, may occur without policy, as they also provide private benefits. For example, firms investing in improved energy efficiency lower their energy costs. However, even these investments will be less than optimal without climate policy, as firms will not incorporate the external benefits of reduced carbon emissions in their decision making.

adopt clean technology. Given the needs for continued development, developing countries are unlikely to enact policies requiring binding carbon emissions reductions at this time. Instead, incentives for these technology flows occur as a result of developed country commitments. For example, most transfers of climate-friendly technology to developing countries currently occur through the Clean Development Mechanism, which allows developed country actors to meet emissions reduction limits by sponsoring projects in developing countries. This poses a challenge for estimating the costs and benefits of technology transfer, as these transfers do not occur independent of other climate policies. To address this, Yang looks at the incremental gains from technology transfer, by considering the cost savings that result compared to a base case with comparable emissions reductions, but no technology transfer. Nonetheless, when comparing the cost-benefit estimates of the technology transfer option to other policies, it is important to keep in mind that technology transfer *by itself*, is not sufficient.[4]

Second, technology transfer comes in many forms. As Yang notes in his paper, technology transfer can be direct or indirect. Direct transfers include those modeled in the paper, in which developed countries finance carbon mitigation projects in developing countries. The mitigation technology is available for use in the recipient country only because of the financing provided by the developed country. Direct transfers could also come via international trade, particularly in the case where a technological advance is embodied in the product being traded. For the modeler, data on direct transfers are readily obtainable, and thus are straightforward to include in policy assessments.

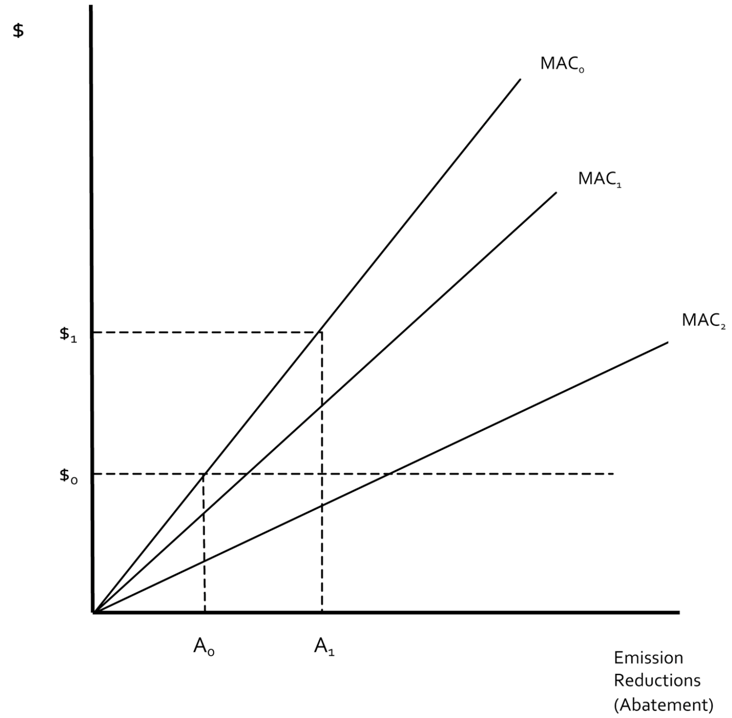
In contrast, indirect technology transfers involve disembodied knowledge. Examples include demonstration projects, training local staff, and local firms hiring away staff from multinational firms operating in a developing country. Disembodied technology transfer provides the well-known spillovers often cited in the productivity literature. Spillovers occur when the provider of a technology is not fully compensated for the gains realized by the recipient. To consider the importance of these spillovers, note that the use of advanced equipment provided to a recipient country (embodied technology transfer) may allow the recipient country to reduce carbon emissions. However, such transfers do not necessarily give the recipient country the ability to replicate the technology on their own. In contrast, disembodied technology transfers enable the recipient to develop skills that can be used in later projects initiated by the recipient country, providing a spillover benefit. Because spillovers come from a wide range of activities, they are more difficult to track.

This distinction is important because it affects the future potential of carbon emission reductions in developing countries. One criticism often raised by critics of technology transfer schemes such as the Clean Development Mechanism is the problem of "low-hanging fruit."[5] The low-hanging fruit critique follows from the economic principle of diminishing returns. To the extent that technology transfer to a developing country includes only direct transfer, low cost abatement options will be used up, making future emission reductions more costly.

4 While not related specifically to technology transfer, Popp (2006) finds similar results when studying the viability of R&D subsidies as a climate policy tool. Compared to a combined policy using both optimal carbon taxes and R&D subsidies, a policy using only the optimal R&D subsidy attains just 11% of the welfare gains of the combined policy. In contrast, a policy using only the carbon tax achieves 95% of the welfare gains of the combined policy.

5 See, for example, references in footnote 1 of Narain and van't Veld (2008).

Figure 2 – Low-Hanging Fruit and Knowledge Spillovers



In Figure 2, the marginal abatement cost curve MAC_0 represents the costs associated with current technologies in developing countries. Initial abatement levels are A_0, with marginal costs $\$_0$. Financial transfers increase abatement to A_1, raising the marginal abatement cost to $\$_1$. As a result, future abatement efforts by developing countries will cost more – the "low-hanging fruit" effect. This cost increase can be offset if the transfers include spillovers that lower the marginal abatement cost. Here, MAC_1 represents a shift which partially offsets the "low-hanging fruit" effect, while MAC_2 represents a shift where new technologies completely offset the "low-hanging fruit" effect, so that further abatement is possible at a marginal abatement cost less than $\$_0$.

Proponents of the "low-hanging fruit" theory worry that if developed countries receive credit now for performing the cheapest emissions reductions options in developing countries, these options will be unavailable for later use by developing countries. As such, these countries will be worse off when later attempting to reduce emissions on their own, and will be less willing to agree to binding emissions reductions at a later date.[6] In essence, such projects move a country to a higher point on their marginal abatement cost curve, as shown by the first marginal abatement cost curve (MAC_0) in Figure 2.

However, technology transfer can counteract the impact of diminishing returns. While it is true that the costs of additional emissions reductions *at a given time* will increase as more projects are completed, the arrival of new technologies provide new opportunities for emissions reductions, so that the future costs of reducing emissions can be lower. In particular,

6 Note that developing countries can be compensated for future cost increases, so that CDM projects become mutually beneficial. Indeed, since such projects require the voluntary agreement of all parties, one would expect such compensation to take place (Narain and van't Veld, 2008; Rose *et al*. 1999). However, even if compensation is received, so that the recipient country isn't made worse off, the developing country recipient may still delay undertaking their own emissions reductions and participating in future treaties if the easiest options for lowering emissions have already been exhausted.

disembodied technology transfers shift the marginal abatement cost curve in, making future emission reductions less costly. This shift will partially (MAC_1 in Figure 2) or completely (MAC_2 in Figure 2) offset the low-hanging fruit problem. By lowering future marginal abatement costs, such technology transfers also increase the possibility that developing countries will agree to future emission constraints.

Given these dynamic concerns, the potential benefits from knowledge spillovers are quite high, and are likely to exceed the benefits of direct technology transfer. Nonetheless, Yang's decision to ignore these spillover benefits, focusing instead on the direct transfer benefits, is defensible, given the third challenge of modeling technology transfers – a lack of empirical evidence on the magnitude of spillovers across countries. Measuring direct flows is straightforward. International trade data, for instance, provide evidence of flows of technologies across countries. However, estimating the spillover benefits is more challenging. In the broader literature on technological change, economists consistently find that knowledge spillovers within countries result in a wedge between private and social rates return to R&D. Examples of such studies include Mansfield (1977, 1996), Pakes (1985), Jaffe (1986), Hall (1996), and Jones and Williams (1998). Typical results include marginal social rates of return between 30 and 50 percent, suggesting social rates of return about four times higher than private rates of return. However, few studies provide empirical evidence on the extent to which these gains flow to developing countries.

While estimates of the magnitude of spillovers to developing countries are hard to find, several studies provide evidence of the existence of spillovers to developing countries. The focus of these studies is oriented more towards microeconomics, making it difficult to directly incorporate the results into a macroeconomic climate model such as RICE. However, they provide some insight as to the potential for spillover benefits from technology transfer to developing countries. The method of technology transfer (e.g. via international trade or FDI) matters, with spillovers less likely to occur when foreign direct investment is the method of transfer, as firms choose FDI when they want to keep knowledge internal (Saggi 2000, Keller 2004). The absorptive capacity of the recipient country is also important. Absorptive capacity describes a country's ability to do research to understand, implement, and adapt technologies arriving in the country. It depends on the technological literacy and skills of the workforce, and is influenced by education, the strength of governing institutions, and financial markets (World Bank 2008). Countries with greater absorptive capacity are more likely to receive spillovers from technology transfer.

3. TECHNOLOGY TRANSFER IN YANG'S MODEL – IMPLICATIONS AND EVIDENCE

Yang uses two scenarios to evaluate technology transfer. In the first, only the developed countries face binding emission constraints. Technology transfer takes the form of financial transfers used to finance carbon abatement activities in developing countries. As these countries do no other abatement, the marginal costs of these sponsored abatement projects are low. In the equilibrium, marginal abatement costs are equated across regions, resulting in minimized abatement costs. While labeled as "technology transfer", one could generate the same result by modeling a global tradable permit scheme in which developing countries were given sufficient permits to cover all current emissions.

In the second scenario, developing countries voluntarily undertake some emission reductions. Countries consider the damages that they face from climate change, and abate until their marginal cost of abatement equals ***their own*** marginal damage. Thus, abatement in developing countries is insufficient, as it ignores the value of damages to other countries, but is no longer zero. Given Yang's setup, in which technology transfer takes the form of financial transfers, the net benefits of technology transfer are lower in this scenario, as some low-hanging fruit are picked by the developing country before transfers occur.

These two contrasting results illustrate the importance of omitting the dynamic effects of technology transfer. By modeling technology transfer as a simple movement along the marginal abatement cost curve, the largest possible gains occur when developing countries take no unilateral action. However, allowing technology transfer to shift the marginal abatement cost curve could change the results. In this case, lowering marginal abatement costs enables developing countries to take more unilateral action. This would be expected to close the gap in net benefits between these two scenarios. Whether the ordering of policies would change is unknown, and depends upon the magnitude of the shift of the marginal abatement cost curve.

While acknowledging the importance of knowledge spillovers, Yang omits these benefits from his analysis because of a lack of empirical evidence on their magnitude. This same lack of information makes it difficult to know whether the marginal abatement cost shift described above would be sufficient to change the ordering of the two policy simulations. Nonetheless, there are two studies that provide some guidance as to the likely importance of spillovers.

The importance of absorptive capacity for spillovers is captured by Bosetti ***et al*** (2008). This paper uses the WITCH model, which is based on the RICE model used by Yang. The WITCH model includes more technological detail than the RICE model, allowing for endogenous technological change that can potentially improve energy efficiency or the production of energy from various sources, including renewable energy. To model technology transfer, WITCH includes a global stock of knowledge for each of the technology options described above. The ability to use this knowledge varies by country, depending on a country's absorptive capacity. The model treats technology differently in developed and developing countries. Innovation from developed countries sets the technological frontier, which is readily available to all high-income countries. Developing countries do not contribute to the technological frontier. Instead, each has its own knowledge stock which consists of knowledge absorbed from the technological frontier. The ability of a developing country to use knowledge from the technological frontier depends on absorptive capacity. Absorptive capacity varies by country, and is higher for countries whose own knowledge stocks are closer to the technological frontier.

In the WITCH model, technology transfer takes a different form than in Yang's simulation. Bosetti ***et al***. first simulate the effects of a global permit trading policy stabilizing CO_2 emissions at 450 ppm. With the exception of having a more stringent standard than Yang, this is otherwise identical to Yang's technology transfer case, as the trading results in marginal abatement costs being equal across regions. Technology transfer is then considered as a special case, in which the permit market is augmented by a policy in which the revenue from permit sales is used to build absorptive capacity in developing countries. Such aid is analogous to the spillovers discussed earlier, as it results in a shift of the marginal abatement cost curves of developing countries. The amount of aid made available varies over time, from $2 billion (in 1995 US dollars) in 2007, to $105 billion in 2062. Thus, the amount transferred is greater than in Yang's simulation, in which the optimal transfer peaks at just over $50 billion (in 2000 US dollars). The resulting increase in technology in developing countries reduces their climate stabilization costs by 2.3 percent.[7] To further ascertain the benefit of the spillovers themselves, the authors simulate the effect of lump sum income transfers equal to the amount of technology transfer funding. There, stabilization costs fall by just 1.55 percent, suggesting that technology transfer resulting in spillovers is nearly 50 percent more effective at reducing abatement costs.[8]

While the WITCH model provides some evidence of the importance of spillovers, it is a simulation model, and must make assumptions about key technology transfer parameters, given the lack of good empirical estimates on these spillovers. One recent study that provides some evidence comes from Dechezleprêtre, Glachant, and Ménière (2008). These authors consider whether CDM projects have a technology transfer component. They look at 644 CDM projects registered by the Executive Board of the UNFCCC, asking how many projects transfer "hardware", such as equipment or machinery, as opposed to "software", which they consider to be knowledge, skills, or know-how. That is, how often do CDM projects transfer knowledge and skills that not only allow a developed country investor to meet emission reduction credits, but also enable the recipient developing country to make continual improvements to their own emission levels? The results provide some insight as to the likelihood that the types of transfers modeled in Yang's simulation may result in knowledge spillovers.

Dechezleprêtre, Glachant, and Ménière find that 279 projects, or 43%, involve technology transfer. However, these projects are among the most significant CDM projects, as they account for 84% of the expected emissions reductions from registered CDM projects. Of these projects, 57 transfer equipment, 101 transfer knowledge, and 121 transfer both equipment and knowledge. The percentage of projects involving technology transfer varies depending on the type of technology used in the project. For instance, all projects reducing trifluoromethane (HFC-23) involve transfer, but this is solely a transfer of equipment. Most projects reducing nitrous oxide and recovering methane also involve equipment transfer, as do renewable energy projects such as wind and solar. In contrast, energy efficiency measures are less likely to include technology transfer. Technology transfer also varies by recipient country. Just 12% of the projects studied in India include technology transfer, compared to 40% in Brazil and 59% in China.

While the results of these two studies are not directly comparable to Yang's simulation, they do enable a "back of the envelope" calculation of the additional gains that might arise in Yang's model were spillovers considered. First, Bosetti ***et al***. find that, compared to lump sum income transfers, the spillovers that result from improving absorptive capacity reduce climate

7 Unfortunately, Bosetti *et al.* do not provide magnitudes of the cost savings, so that direct comparisons to Yang's results are not possible.

8 Note that a direct comparison to Yang's result is not possible from the information in Bosetti *et al*. (2008). Yang's simulation shows the benefits from equating marginal abatement costs across regions. This, however, is Bosetti *et al*.'s base case. The 2.3 percent cost reduction in Bosetti *et al.* represents the gains from moving to a base case where marginal abatement costs are equal across regions, to a world where marginal abatement costs are equal *and* technology transfers improve the absorptive capacity of developing countries.

mitigation costs by 50%. From Dechezleprêtre, Glachant, and Ménière, approximately two-thirds of all emission reductions from CDM transfers involve knowledge transfer.[9] If we assume that the spillover results from Bosetti *et al*. only apply to two-thirds of the transfers in Yang's model, the cost savings from technology transfer would increase by one-third.

4. CONCLUSIONS

Evaluating technology transfer as a policy option has several complications. Most importantly, technology transfer by itself is not a policy option. Technology transfer will not be effective unless countries face binding emissions constraints compelling them to reduce emissions, rather than using newly acquired technologies to increase output. This is consistent with other findings in the climate policy simulation literature showing technological advances augmenting the effects of policy, but in a secondary role. Instead, direct factor substitution in response to policy incentives is more important (Nordhaus, 2002).

Moreover, while encouraging emissions reductions in developing countries is important, most near-term reductions will come from developed countries. The limited role for developing country reductions helps reconcile two results in the preceding section. While we find that accounting for spillovers would significantly lower Yang's cost estimates, it is also the case that Bosetti ***et al***. find that simulating spillovers reduces mitigation costs by just over two percent. This is consistent with the small role that developing countries play. While spillovers may greatly decrease the cost of emissions reductions in these countries, emissions reductions in developing countries are still just a small share of global emissions reductions.

As a result, while technology transfer should not be considered as an isolated option, it is likely to play an important role as part of a broader policy package. Carbon emissions from developing countries are growing at the same time that developed countries begin to reduce their own emissions. Given their need for continued economic growth, developing countries are unlikely to agree to constrain emissions without compensation from developed countries. Technology transfer provides one such form of compensation.

The effectiveness of this technology transfer depends on the nature of the transfer. As modeled in Yang's simulation, technology transfer provides significant short-term gains, as marginal abatement costs are equalized across regions. However, as the financial transfers in Yang's model do not shift the marginal abatement cost curve of developing countries, future emissions reductions from developing countries will cost more than they would have without the transfers. By raising the future abatement costs of developing countries, this makes their future participation in a climate treaty less likely. In contrast, technology transfers that shift the marginal abatement cost of developing countries may offset the "low-hanging fruit" problem described here, making future participation more likely. Because Yang focuses on tangible gains that can be readily modeled, he acknowledges that such gains are not considered in his model. While this is reasonable given the need to produce a concrete number, it also suggests limitations to focusing on only measurable impacts of technology transfer.

9 The calculation is as follows: projects involving technology transfer account for 84% of the emission reductions from CDM projects. Of the 279 projects with technology transfer, 222 (80%) involve a transfer of knowledge. Multiplying these two percentages yields 67%.

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The science is clear. Human-caused global warming is a problem that we must confront.

But which response to global warming will be best for the planet? The Copenhagen Consensus Center believes that it is vital to hold a global discussion on this topic.

The world turned to scientists to tell us about the problem of global warming. Now, we need to ensure that we have a solid scientific foundation when we choose global warming's solution. That is why the Copenhagen Consensus Center has commissioned research papers from specialist climate economists, outlining the costs and benefits of each way to respond to global warming.

It is the Copenhagen Consensus Center's view that the best solution to global warming will be the one that achieves the most 'good' for the lowest cost. To identify this solution and to further advance debate, the Copenhagen Consensus Center has assembled an Expert Panel of five world-class economists – including three recipients of the Nobel Prize –to deliberate on which solution to climate change would be most effective.

It is the Copenhagen Consensus Center's hope that this research will help provide a foundation for an informed debate about the best way to respond to this threat.

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