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International Technology Transfer for Climate Policy

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Policy Brief

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Introduction

While the developed world is starting to limit emissions of greenhouse gases, emissions from the developing world are increasing as a result of economic growth. Reducing these emissions while still enabling developing countries to grow requires the use of new technologies. In most cases, these technologies are first created in high-income countries. Thus, the challenge for climate policy is to encourage the transfer of these climate-friendly technologies to the developing world.

This policy brief reviews the economic literature on environmental technology transfer. It then discuss the implications of this literature for climate policy, focusing on the Clean Development Mechanism (CDM) of the Kyoto Protocol. It concludes by asking whether the current structure of the CDM provides sufficient incentives for technology transfer. Are CDM projects providing real emissions reductions, or are developed countries simply receiving credit for reductions that developing countries could have achieved on their own? What lessons can we learn from recent experience that may guide the development of the CDM (or other similar policy tools) during the next round of international climate policy negotiations?

Global Warming and the Kyoto Protocol

Greenhouse gases (GHGs) are the gases present in the earth's atmosphere that reduce the loss of heat into outer space. Strong scientific evidence indicates that excess GHGs trap heat and raise the temperature of the earth's atmosphere to a level that causes undesirable climate changes. The most important greenhouse gases include water vapor, carbon dioxide (CO_2), methane, and ozone. While many natural processes produce GHGs, most scientists agree that anthropogenic (human) activity, particularly burning carbon-based fossil fuels, has increased the concentration of CO_2 and some other GHGs since the Industrial Revolution began in the mid-1700s. Although it is not easy to know precisely how long it takes GHGs to leave the atmosphere, most take several years.

The international response to climate change began at the Earth Summit in Rio de Janeiro in 1992, where more than 150 countries signed the UN Framework Convention on Climate Change, a non-binding agreement to stabilize GHG emissions at 1990 levels by the year 2000.

Subsequently, the 1997 Kyoto Protocol set binding targets on 37 industrialized countries and the European Community to reduce emissions 5.2 percent below 1990 levels by 2012. Since most anthropogenic GHGs were created during the past 150 years of industrial activity by developed countries, the Protocol placed a greater responsibility on those countries to reduce GHG emissions. The Protocol legally entered into force on February 16, 2005, and has been ratified by 180 countries to date.

The Kyoto Protocol provides three market-based “flexibility mechanisms” to help countries meet their GHG emission targets.

- **Emissions Trading** allows countries that have more emission units than they need to sell the excess units (called assigned amount units, or AAUs) to countries that are over their targets. A new commodity has been created in the form of emission reductions or removals, known simply as the carbon market. These transactions take place between Annex I countries (developed and transitioning countries that have ratified the Protocol; see Appendix for a list of Annex I countries).

- **Clean Development Mechanism (CDM)** allows Annex I countries with emission constraints to receive credit toward their own country’s emissions reduction target by investing in projects that reduce emissions in developing countries that do not face emission constraints. Developed countries can thus reach their emission targets at a lower cost to themselves by substituting emissions reduction projects in developing countries, where costs are lower, for more expensive projects in the home country.

- **Joint Implementation (JI)** enables any Annex I country to meet its emissions reduction commitment by investing in a project in any other Annex I country as an alternative to reducing emissions in their own country. In practice, most JI projects are expected to take place in transitioning Annex I countries, where costs are lower.

Recent rapid economic growth of countries such as China and India brings the promise of a better life to much of the world's population. However, with growth comes pollution, particularly greenhouse gas emissions such as carbon dioxide that lead to climate change. The need to reduce global CO_2 emissions comes at a time when the share of emissions coming from developing countries is growing. From 2003 to 2004, CO_2 emissions from developed countries that are members of the Organization for Economic Cooperation and Development (OECD) grew by less than 2 percent, while those from non-OECD countries grew by nearly 10 percent. Energy-related CO_2 emissions from non-OECD countries exceeded those from OECD countries for the first time in 2004 (Energy Information Administration 2007). Much of this increase can be attributed to economic growth in China and India. In 1990, these two countries accounted for 13 percent of world CO_2 emissions. By 2004, that figure had risen to 22 percent, and it is projected to rise to 31 percent by 2030.

But CO_2 persists in the atmosphere for hundreds of years, and developed countries are responsible for nearly all of the increase in carbon concentrations that has occurred since the Industrial Revolution. Through the principle of "common but differentiated responsibilities," the Kyoto Protocol places the burden of reducing carbon emissions on those countries responsible. Although the United States has not ratified the Kyoto Protocol, other Annex I nations have, and plans to reduce CO_2 emissions have been introduced in many of these countries.

During negotiations for the successor to the Kyoto Protocol, emissions from developing countries will receive increased attention. Indeed, one of the primary objections of US policymakers to Kyoto is the lack of reduction commitments for developing countries. However, forcing mandatory emissions limits on developing countries will be difficult because they also face internal pressures to develop and modernize their economies and provide a higher standard of living for their citizens. Burning fossil fuels, the main source of GHG emissions, increases as a country's economy grows.

Developing and Transferring New Technologies

Reducing GHG emissions while accommodating both economic growth and population growth depends on one of two strategies (Holden 2006).

- Reduce the *carbon intensity* of energy use (that is, the amount of carbon emitted per unit of energy consumed). This ratio has been falling over time, as the deployment of cleaner energy sources such as natural gas and wind increases. However, this will be a particular challenge in China, which currently receives about 68 percent of its energy from coal, the most carbon intensive of the fossil fuels (Yardley and Revkin 2007).

- Reduce *energy intensity* (energy usage per dollar of GDP) by improving energy efficiency. More efficient technologies enable a country to achieve greater economic output from a given amount of energy.

Both strategies require developing new and improved technologies, and then transferring them from developed to developing countries. Most technological innovation currently takes place within a few highly developed economies. In 2000, global research and development (R&D) expenditures were at least $729 billion. More than 80 percent of this R&D was conducted in the OECD, half by the United States and Japan alone (National Science Board 2006). Thus, an important question for policymakers as they negotiate a successor to Kyoto is how to encourage the development and deployment of energy efficiency and alternative energy technologies in the developing world.

Although the Kyoto Protocol does not impose binding emissions reductions on developing countries, it offers the Clean Development Mechanism (CDM) as a means by which developed nations can help developing countries reduce their emissions. Under the Kyoto Protocol, reducing GHG emissions (which are measured in millions of tons of CO_2

equivalent) by means of CDM projects has grown from just under 100 million tons in 2004 to nearly 550 million tons in 2007. As expected, given the European Union's active role in reducing CO_2 emissions, most of the investors are European countries, which sponsored 87 percent of CDM and Joint Implementation projects, with Japan accounting for another 11 percent (Capoor and Ambrosi, various years).

Technological Change and the Environment: Theory and Evidence

Technological change proceeds in three stages. At each stage, incentives in the form of prices or regulations affect the development and adoption of new technologies. Joseph Schumpeter (1942) described the process of technological change as one of "creative destruction":

- *Invention:* an idea must be born.

- *Innovation:* new ideas are then developed into commercially viable products. Often, these two stages of technological change are lumped together under the rubric of research and development (R&D).

- *Diffusion:* to have an effect on the economy, individuals must choose to make use of the innovation.

Market Failures in Research & Development

At all three stages, market forces provide insufficient incentives for investment in either the development or diffusion of environmentally-friendly technologies. Economists point to two market failures as the explanations for underinvestment in environmental R&D.

One is the traditional problem of *environmental externalities.* Because carbon emissions created in the production of a product are not normally included in the price of the product, neither firms nor consumers have any incentive to reduce emissions on their own. Thus, the market for technologies that reduce emissions is limited, which in turn reduces the incentives to develop such technologies. However, even in the absence of policy interventions, there will likely be <u>some</u> incentives to develop technologies that reduce carbon emissions. Such technologies may come with private benefits—for example, reduced gasoline expenditures from switching to a hybrid-powered automobile. The market failure problem simply means that individuals do not consider the social benefits of using technologies that reduce emissions.

The second market failure pertaining to R&D is the *public goods nature of knowledge* (see, for example, Geroski 1995). In most cases, new technologies must be made available to the public for the inventor to reap the rewards of invention. However, when this happens, some or all of the knowledge embodied in the invention also becomes available to the public. This public knowledge may lead to *knowledge spillovers*—additional innovations, or even copies of the current innovations, which provide benefits to the public as a whole but not to the innovator. As a result, private firms do not have incentives to provide the socially optimal level of research activity.

The technological innovations discussed in this brief will typically include knowledge spillovers, as it is nearly impossible for the firm transferring a technology to be fully compensated for the enhanced productivity the recipient will enjoy when employing the newly-received skills in future projects. Because firms cannot be fully compensated for these knowledge spillovers, climate-friendly R&D will be underprovided by market forces even if policies to correct the environmental externalities of emissions, such as carbon taxes, are in place.

Current Findings for Environmentally-Friendly Innovation

- **Nearly all of the world's R&D is performed in the developed OECD economies, so their climate policies usually shape the development of climate-friendly technologies.**

Lanjouw and Mody (1996) study technological change for a variety of environmentally-friendly technologies, using patent data from the US, Japan, Germany, and 14 low- and middle-income countries. They find that such innovation increases as pollution abatement expenditures in the country increase. For the US, Japan, and Germany, the majority of these patents are typically domestic patents. In contrast, for the developing countries, the majority of these patents come from foreign countries. This is especially true of air pollution control technologies, which are typically complex. Water pollution control technologies, on the other hand, are more frequently local innovations, as local conditions shape the requirements of these technologies, and they are less likely to be patented elsewhere.

- **Policies in one nation may affect innovation of technologies in a second nation.**

For example, the United States was the first country to adopt strict automobile emissions standards, but the majority of vehicle air emissions patents granted in the US are from foreign nations (Lanjouw and Mody 1996). Korean automotive manufacturers first incorporated advanced emission controls into their vehicles to satisfy regulatory requirements in the US and Japanese markets (Medhi 2008), and only later did the Korean government pass their own regulations requiring advanced emission controls.

However, inventers of air pollution control technologies for coal-fired electric power plants in the US, Japan, and Germany respond primarily to domestic regulatory incentives (Popp 2006). In each country, the largest increase in domestic patent applications occurs after the country passes regulations affecting power plants. One reason why foreign markets may have little influence on innovation in the electricity sector, as opposed to the automotive industry, is that electricity is not a traded commodity. Moreover, the bulk of emissions control equipment used in these countries comes from domestic suppliers.

- **Adaptive R&D seems to be necessary to suit the technology to the local market in developing countries.**

Popp finds evidence of innovation even in countries that adopt regulations late, suggesting that these countries do not simply take advantage of technologies “off the shelf” that have been developed elsewhere. Instead, late adopters often undertake adaptive R&D to fit the technology to local markets. As evidence, Popp finds that these later patents are more likely to cite earlier foreign rather than domestic inventions. Lanjouw and Mody find similar evidence that the environmentally friendly innovations that do occur in developing countries are smaller inventive steps, typically done to modify existing technologies to local conditions. Foreign knowledge serves as blueprints for further improvements, rather than as a direct source of technology.

When policymakers consider the potential for technological change to reduce climate emissions in developing countries, they must make allowances for adaptive R&D to fit technologies to local conditions, or else be prepared for less than desired results when the transferred technology is not a perfect fit for the local market.

- **Binding emissions constraints in developing countries will not be necessary to encourage the invention and innovation of technologies that reduce carbon emissions.**

Policies in developed countries encourage innovation of emissions-reducing technologies. For example, patenting activity for renewable energy technologies, measured by applications for renewable energy patents submitted to the European Patent Office (EPO), has increased dramatically in recent years, as both national policies and international efforts to combat climate change begin to provide incentives for innovation (Johnstone et al. 2008). 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 a result, technologies to help reduce emissions in developing countries are available for adoption.

Transfer of Environmentally Friendly Technologies

As innovation of technologies to reduce GHGs is already underway in developed countries, the key question for developing countries is one of technology transfer. The current availability of cleaner technologies offers developing countries a chance to leapfrog over developed economies by adopting them before more serious harm occurs (see Dasgupta et al. 2002). For instance, China's 2006 *Report on the State of the Environment* declares scientific innovation the key to "historic transformation of environmental protection" and "leap-frog development." As an example of this, when China imposed their first fuel economy regulations on passenger vehicles in 2004, the standards were more stringent than those in place in the United States (Bradsher 2004). However, as discussed below, it is still important for proper incentives to be in place for these transfers to occur.

What is Technology Transfer?

There is no one universally accepted definition of technology transfer. Pertaining to climate change, the Intergovernmental Panel on Climate Change (IPCC) defines *technology transfer* as:

> 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, non-governmental organizations (NGOs) and research/education institutions. (IPCC 2000, quoted in Seres et al. 2007)

The benefits of the transfer to the recipient developing country, and thus the potential for technology transfer to improve well-being in the recipient country, depend on the type of transfer.

Embodied technology transfer comes through the importation of equipment into a country (e.g., flows of equipment). In such cases, the technology is *embodied* in the imported equipment.

Disembodied technology transfer involves the flow of know-how or experience. Examples include demonstration projects, training local staff, and local firms hiring away staff from multinational firms operating in a developing country.

The benefits of each type of technology transfer are best illustrated by the old Chinese proverb: “Give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime.” The use of advanced equipment imported into the country (embodied technology transfer) may make the recipient country more productive, just as eating fish received as a handout may make the recipient less hungry. However, such transfers do not necessarily give the recipient country the ability to replicate the technology on their own. In contrast, just as teaching a man to fish enables the learner to provide for himself, disembodied technology transfers enable the recipient to develop skills that can be used in later projects initiated by the recipient country.

At the same time, disembodied technology transfers are a concern for private firms because they result in *knowledge spillovers,* or the unintentional transmission of knowledge beyond the boundaries of the firm. For instance, multinational corporations (MNCs) often go to great lengths to keep local workers from leaving their firm to work for a local company, in order to prevent knowledge from falling into a competitor's hands. These corporations often pay higher wages than local firms to give workers an incentive to stay.

Sources of Technology Transfer

Public funding of technology transfer includes aid from governments or non-governmental organizations (NGOs), typically in the form of official developmental assistance (ODA). Compared to private investment, ODA flows are small, but they are important in areas of the world that receive little foreign investment (Gupta et al. 2007). In the case of climate change, such aid often involves international cooperation. For example, the United Nations Development Program (UNDP), United Nations Environment Program (UNEP), and World Bank jointly implement the Global Environment Facility (GEF), which provides grants for developing country projects to protect the global environment. Although not devoted specifically to climate change, biodiversity and climate change are the two most important categories funded by GEF. Since 1991, GEF has invested almost $2 billion for climate change, of which 90 percent has gone to energy efficiency, renewable energy, GHG reduction, or sustainable transportation (de Coninck et al. 2008).

Private firms transfer technology to developing countries in three ways.

Trade. A developing country may acquire new technology via international trade, with the technology embodied in the good being traded. Trade is an increasingly important source of new technologies; the share of GDP attributed to imported high-tech products has grown by over 50 percent in low-income countries, and by over 70 percent in middle-income countries, since 1994 (World Bank 2008).

Spillovers are possible through trade, depending on the *absorptive capacity* of the country. Absorptive capacity describes the recipient country's ability to do research to understand, implement, and adapt technologies arriving in the country. Absorptive capacity influences the speed at which a newly arriving technology diffuses through a developing 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 (see World Bank 2008 for a discussion of the role of absorptive capacity in technology transfer).

Foreign Direct Investment. Using foreign direct investment (FDI), a multinational corporation (MNC) establishes a subsidiary in the recipient country and makes use of advanced technology in the subsidiary. FDI flows into developing countries rose from $10 billion in 1980 to $390 billion in 2007 (World Bank 2008).

The beneficiary of technology transfer through FDI varies. In some cases, the MNC may reap the rewards of using the new technology (e.g., via enhanced productivity and greater profits). In other cases, local firms may learn about the technology (e.g., through workers who leave the MNC to work at a locally-owned company). In such cases, spillovers occur and the developing country's technological base is enhanced. However, empirical studies on FDI in developing countries find little evidence of technological spillovers from FDI (Saggi 2000, Keller 2004). Once again, absorptive capacity is important, as spillovers are most likely when the difference in technological sophistication between countries is not large (World Bank 2008).

License to a Local Firm. A multinational firm may instead choose to license its technology to a firm in the recipient country. Developing countries paid $22 billion in licensing fees in 2006, which, as a percentage of developing country GDP, represents a five-fold increase between 1999 and 2006 (World Bank 2006). Licensing allows the MNC to avoid potential trade barriers when sending technology abroad, and to gain entry to countries where they are uncertain about local markets or customs. However, depending on the terms of the licensing agreement, the MNC may give up some control over the technology. The strength of intellectual property rights is important here, as stronger intellectual property rights make it easier for the MNC to protect its technology and thus more willing to license it. At the same time, stronger intellectual property rights make spillovers to developing countries less likely.

Because firms become less concerned with technology leaking out as an innovation becomes older, firms tend to choose FDI to transfer newer technologies and licensing to transfer older technologies that are no longer cutting edge (Mansfield and Romeo 1980).

Incentives to Transfer Climate-Friendly Technology

Given these pathways for technology transfer, it is important to consider the incentives that exist for adopting climate-friendly technology. These depend on the nature of the technology and the extent to which environmental externalities are corrected by environmental policy.

- **Energy efficient innovations diffuse even without environmental policy.**

First, consider emissions reductions achieved using energy efficient technologies. Private firms have incentives to make such investments even without climate policy in place, as reducing energy consumption provides cost savings to the firm. For example, Fisher-Vanden et al. (2006) studied energy consumption at 22,000 Chinese large and medium enterprises, and found that total energy use fell by 17 percent between 1997 and 1999. About half of this decline can be explained by price changes. Technological change, measured by firm-level R&D, accounted for 17 percent of this change, and changes in ownership accounted for another 12 percent.

They also found that a firm's in-house technological activities are important for creating absorptive capacity needed for successful diffusion of imported technology. That is, local firms are more likely to successfully transfer technology from abroad if they are actively involved in R&D themselves. Similarly, Fisher-Vanden (2003) studied the diffusion of continuous casting technology for steel production at 75 Chinese steel firms. The use of continuous casting has important energy implications, as it uses 70 percent less energy than ingot casting. Fisher-Vanden found that while centrally managed firms are the first to acquire new technology, locally managed firms complete the integration of the technology throughout the firm more rapidly.

As both these studies illustrate, energy efficient technologies will diffuse to developing countries even without the aid of policy, as firms (particularly privately owned, profit maximizing firms) look to lower production costs. Since 1980, *energy intensity*, defined as energy consumption per dollar of GDP, has fallen at a rate of nearly 4 percent per year in China. Worldwide, energy intensity has fallen at a rate of 1.5 percent per year since 1995 (Energy Information Administration n.d.). However, without policies limiting carbon emissions, firms will underinvest in energy efficient technologies, as the additional environmental benefits achieved by these technologies do not enhance the firm's bottom line.

- **Without environmental policy, firms do not have incentives to adopt costly technologies that reduce emissions but provide no additional cost savings to the firm.**

In other cases, reducing emissions requires firms to take costly actions that provide no direct benefits to the firm itself. Examples of such technologies for climate change include clean energy sources such as wind and solar, which produce no carbon emissions but cost more than fossil-fuel based energy sources; capture of methane gas from landfills; and carbon sequestration from power plants.

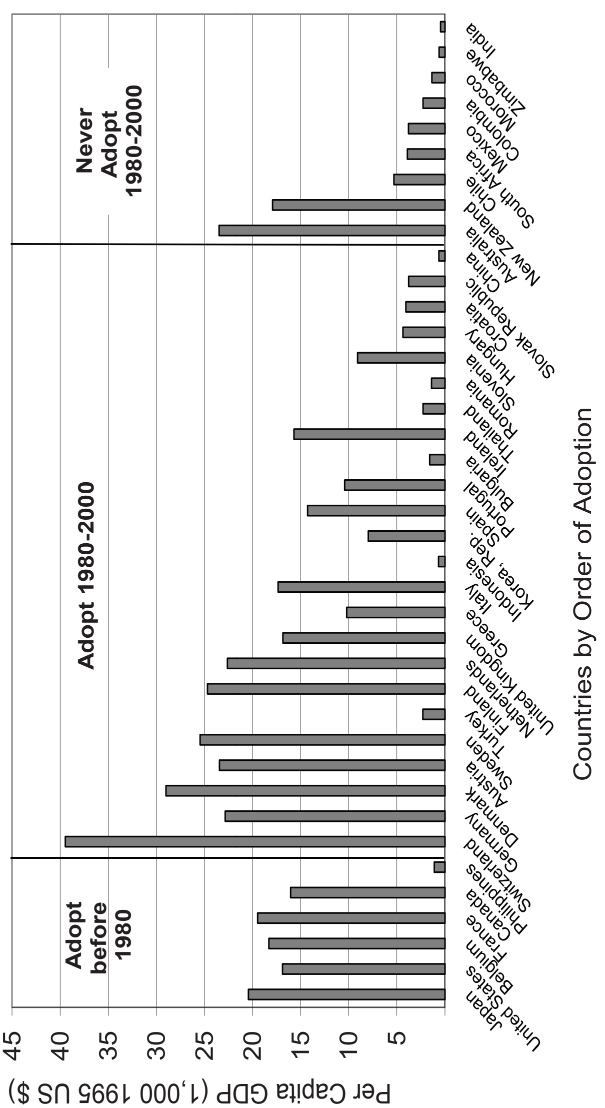
Because most policies reducing carbon emissions are only a few years old, little evidence of the effect of these polices on technology diffusion exists. Instead, we can draw analogies from the study of older air pollution technologies. For instance, since regulations limiting particulate matter (PM) were enacted several years before regulations covering sulfur dioxide (SO_2) and nitrogen oxides (NO_X), most power plants in China have controls for particulate matter, while only the newest plants control NO_X and SO_2 (Lovely and Popp 2008). Similarly, Gallagher studies joint ventures between US and Chinese automobile firms. All of them transfer environmental technology to China, but it is not advanced. In most cases, emissions control technologies used in autos in China comply with older Euro II standards, which are required for Beijing and Shanghai, but would not meet developed country standards. Gallagher notes that "(t)he main reason cleaner and more energy-efficient technologies were not transferred is that there simply were no compelling policy incentives for the US firms to do so, and the foreign firms did not voluntarily transfer better technologies" (2006, p. 387).

Because most pollution control technologies are first developed in industrialized countries, and because environmental regulations are needed to provide incentives to adopt these technologies, adoption of regulation is a key first step in the diffusion of climate-friendly technologies. While the adoption of pollution control technologies within a country responds quickly to environmental regulation, adoption of the regulations themselves follows the typical S-shaped pattern noted in studies of technology diffusion, in which a few early adopters, typically technology leaders, are followed by a period of more rapid adoption. A period of slower adoption by the remaining stragglers follows.

- **As pollution control technologies improve, the costs of abatement, and thus the costs of adopting environmental regulation, fall. Over time, countries adopt environmental regulation at lower levels of per capita income.**

Lovely and Popp (2008) studied the adoption of regulations limiting emissions of sulfur dioxide and nitrogen oxides at coal-fired electric power plants in 39 countries, both developed and developing, concentrating on the period 1980 to 2000, focusing on access to technology as an important factor influencing regulatory adoption. As pollution control technologies improve, the costs of abatement, and thus the costs of adopting environmental regulation, fall. As a result, over time, countries adopt environmental regulation at lower levels of per capita income. Figure 1 illustrates this trend for the adoption of SO_2 emission regulations. The figure shows per capita GDP, measured in 1995 US dollars, in the year of adoption of SO_2 regulations for each of the 39 countries included in their study. Along the horizontal axis, countries are sorted by the year in which they adopted. The figure is divided into three segments. The first segment includes 6 countries that adopted before 1980, the first year of data in their analysis. With the exception of the Philippines, each of these countries adopted at a per capita income roughly between $15,000 and $20,000. Early adoption of regulation in the Philippines is explained by close bilateral relations with the United States, which includes aid for environmental protection.

Figure 1. Per Capita GDP in Adoption Year



Of the countries adopting SO_2 regulations between 1980-2000, there is a strong trend of countries adopting at lower incomes over time. Lovely and Popp interpreted this trend as showing how the availability of technologies, produced by countries that first chose to adopt SO_2 regulations, lowered adoption costs sufficiently for more countries to be able to afford reducing SO_2 emissions. Moreover, they found countries that are more open to international trade gain access to new abatement technologies sooner, and thus are able to regulate SO_2 emissions sooner. Finally, the third segment of Figure 1 includes countries that have yet to adopt SO_2 regulations. Except for Australia and New Zealand, which choose to not regulate SO_2 emissions because the coal found in these countries is generally low in sulfur, these are all low-income countries (Soud 1991, McConville 1997).

Hilton (2001) also found that late adopters of regulation can learn from early adopters. Using data on 48 nations, he looked at the time it took each country to eliminate lead from fuel, measuring from the date that each country first began phasing out lead in fuel to the date on which the country achieved lead levels at or below 0.5 grams of lead per gallon. Countries that began the process after 1979 completed the lead phase-out five years faster, on average, than those beginning before 1979. Even among countries that did not completely phase out lead, those that began the phase-out process earlier achieved greater reductions. Hilton concluded that late adopters are able to move more quickly because they benefit from lessons learned by early adopters.

Both these studies suggest that advances in technology within developed countries can shorten the time by which developing countries agree to binding emissions reductions. 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.

Applications to Climate Change

Politicians continue to express concerns over non-participation of developing countries, but this is no different from the path taken for other environmental regulations. Developed countries have traditionally acted first, after which the resulting technological innovations made it easier for developing countries to adopt regulations at a later date. There is no reason to expect climate policy to be any different.

However, climate policy is complicated by the fact that GHG emissions reductions are a public good—they benefit everyone, not just the local citizenry. Given this, it is less likely that developing countries will move as quickly to regulate CO_2 emissions as they did in the cases of SO_2, NO_X, and lead. Moreover, developing countries are more likely to accept moderate emissions reductions that could be met by improved efficiency (such as China's climate strategy discussed in the introduction), as the adoption of energy efficiency technologies provides secondary benefits to these countries.

Technological change can also help alleviate the problem of incomplete participation in climate treaties. The standard presumption is that when only some countries commit to reducing carbon emissions, high-carbon industries will migrate to non-participating countries, resulting in *carbon leakage,* an increase in CO_2 emissions in the non-participating countries in reaction to the reduction in emissions by the more strictly regulated countries. Golombek and Hoel (2004) noted that, in the countries committed to carbon reductions, induced technological change will lower abatement costs, which may be sufficient to encourage non-participating countries to reduce their carbon emissions as well. Golombek and Hoel also found the level of environmental R&D in the non-participating country to be important. If the non-participating country is already performing environmental R&D, increases in environmental R&D in the participating country may crowd out R&D in the non-participating country, mitigating the benefits of spillovers. However, if the non-participating country was not doing environmental R&D, as is the case in most developing countries, spillovers will lead to lower emissions. This work is theoretical in nature, and suggests directions for future research. In particular, estimating the magnitude of each effect (technology transfer vs. leakage) would help policymakers better understand the risks (or lack thereof) of incomplete participation.

The Clean Development Mechanism and Technology Transfer

As the previous discussion shows, the transfer of clean technologies to developing countries is important if the growth of carbon emissions from these countries is to be contained. However, 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 adopt clean technology. Given the need for continued economic development, developing countries are unlikely to enact policies requiring binding emissions reductions at this time.

Instead, incentives for these technology flows come from the Clean Development Mechanism, which allows developed countries to meet their own emissions reduction limits by sponsoring projects in developing countries. This section draws on our discussion of international diffusion of environmental technologies to consider the implications of this research for the design and impact of policies such as the CDM.

CDM provides the regulatory incentive to undertake emissions reducing activities in developing countries that do not provide the user with private costs savings, such as lower energy costs. Capturing landfill gas is an example of an emissions mitigation project that would not occur without regulation. CDM also increases the profitability of investing in projects with some private gain, such as improving energy efficiency. Without CDM, firms can reap the benefits of lower energy costs from such investments, but they are not rewarded for the environmental benefits of reduced carbon emissions.

The Kyoto Protocol states two purposes for the CDM: to help developed countries meet emissions reductions obligations and to help developing countries achieve sustainable development (Kyoto Protocol, Article 12.2, 1997). We discuss the role technology transfer plays for each of these goals below.

Does CDM Produce Real Emissions Reductions?

For CDM to achieve real emissions reductions, CDM projects must achieve reductions that could not have occurred without the project taking place. Approved projects should meet three criteria, according to Article 12.5 of the Kyoto Protocol.

1. Participation should be voluntary, and be approved by each party involved.

2. The project should deliver "real, measurable, and long-term benefits related to the mitigation of climate change."

3. Reductions must be "additional to any that would occur in the absence of the certified project activity."

This last criterion, known as *additionality*, has received the bulk of attention from analysts (see Gupta et al. 2007). Less attention has been paid to the prospect of long-term benefits. However, the two concepts are related.

For a project to be registered (and therefore approved) by the CDM Executive Board, the applicant must establish additionality of the emissions reductions. Typically, concerns about additionality focus on <u>current</u> costs and benefits. The UNFCCC (2008) has approved several methodological frameworks for assessing the additionality of proposed CDM projects (http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html). The basic methodology includes four steps:

1. Identify alternative scenarios: What other options are available to project participants? Do these alternatives comply with local regulations?

2. Barrier analysis: Are there barriers to implementing the alternative scenarios? If so, they are not viable alternatives. Are there barriers to completing the proposed CDM project that the project design overcomes?

3. Investment analysis: Is the baseline scenario a better financial investment than the proposed CDM project?

4. *Common practice analysis*: Is the proposed project currently common practice in the area? If so, the emissions reductions are not additional.

To see the link between additionality and long-term benefits, note that CDM project credits extend for several years. Registered projects have a lifespan of 7 or 10 years. According to the CDM Pipeline of approved and potential CDM projects (http://cd4cdm.org/), as of April 2008, 496 of the 978 registered projects had a project length of 10 years, and 481 had a project length of 7 years. (In addition, one reforestation project in China has a project length of 30 years.) As discussed above, environmental technologies have been diffusing to developing countries even without the aid of the Clean Development Mechanism. Given that diffusion is a gradual process, and that CDM credits are valid for multiple years, it is important to ask not only whether a proposed CDM project would be feasible *today* if credits were not available, but also whether the proposed project would be feasible during later years of the credit's lifetime. Carbon emissions are cumulative—that is, they persist in the atmosphere for hundreds of years. If the project would not be viable today, but would be viable in three years time, the CDM credit is not truly reducing global carbon concentrations, but is simply hastening the reduction of emissions by three years. At most, it is only these three years of reduction that are truly additional.

How Might Considerations of Long-Term Benefits Affect Additionality?

First, when determining baseline emissions, the UNFCCC considers continuing the current practice, and then adopting the proposed technology at a later date. However, no guidelines are provided for determining what might be adopted at a later date. The lessons from studies of earlier technological diffusion provide a useful guideline.

In the case of energy efficiency improvements, private actors have incentives to adopt technology even without additional regulatory pressure, so as to lower energy bills. Energy savings are more valuable when energy prices are higher. In this vein, projects that claim credit for improving energy efficiency should be viewed skeptically in a time of rising energy prices. Even if such projects are not currently common practice, one would expect these technologies to diffuse with or without the aid of a CDM project. For example, Fisher-Vanden et al. (2006)

found that, from 1997-1999, both imported and locally developed technologies in China improved energy efficiency.

Some wind power projects may also be viable without CDM support. The general manager of one wind project in China reports that "(w)ithout the Clean Development Mechanism, we'd still be profitable…. (But, we) need the C.D.M. for further expansion" (Bradsher 2007). This is particularly true in areas where the large infrastructure of a traditional fossil-fueled power plant may not be feasible. In contrast, projects without private benefits, such as the capturing of landfill gasses, would be unlikely to occur without CDM support.

Second, consider the criterion of common practice. What is common practice for multinational firms may not be common practice for local firms. Looking at variations in FDI and environmental regulations across Chinese provinces, Dean et al. (2008) found that FDI investment from Hong Kong, Macao, and Taiwan is attracted to provinces with weaker environmental regulation, while FDI from OECD nations is not attracted. Technological differences are important here—OECD multinationals use cleaner technologies elsewhere, and do not necessarily choose to modify their production processes to pollute more when investing abroad. Multinationals are usually the first to bring new environmental technologies to a country (see, for example, Dasgupta et al. 2002). In many cases, it is easier for a multinational firm to use the same equipment and processes that it uses at home, rather than develop a dirtier process for use in developing countries. Thus, the proper evaluation for a CDM project located at a multinational corporation (MNC) subsidiary should ask whether it is common practice for the MNC, rather than whether it is common practice in the host country.

Can CDM Help Developing Countries Achieve Sustainable Development?

By transferring technology to the host country, the Clean Development Mechanism can help lower a developing country's costs of eventual compliance with global climate treaties, and increase the likelihood that developing countries will agree to binding emissions reductions at a later date. While language in the Kyoto Protocol encourages the transfer of climate-friendly technologies, the Clean Development

Mechanism was not explicitly designed with technology transfer in mind. Nonetheless, the potential for technology transfer is an important part of any evaluation of the CDM, particularly when evaluating the long-term benefits that may accrue. Projects that lead to knowledge spillovers through disembodied technology transfer reduce the future costs of lowering emissions. Thus, an important question for evaluating the CDM is whether it encourages projects that include a transfer of knowledge, as opposed to simply a transfer of equipment. Interestingly, the importance of knowledge spillovers is overlooked in many analyses of CDM's impact on sustainable development. Instead, the focus is on broader goals such as poverty reduction, increased employment, and improvement of local environmental conditions (see, for example, Sutter and Parreño, 2007).

Related to technology transfer is a concern often raised by critics of CDM—the problem of "low-hanging fruit" and diminishing returns (e.g., Narain and van't Velt 2008, note 1). Consider the example of trying to reduce energy consumption in your own home. The first steps you can take are straightforward and virtually costless—turning off lights when not in use, lowering the thermostat, and installing compact fluorescent light bulbs. Further reductions in energy consumption, such as replacing older appliances with newer energy efficient models and adding more insulation, would cost much more. Similarly, when considering emissions reductions in a country, the easiest, least expensive projects will probably be done first. To the extent that CDM projects do not involve technology transfer, but rather a developed country investor acting unilaterally, the low cost options will be used first, making future emissions reductions more costly. The recipient developing countries will be worse off when they try to reduce emissions on their own, and less willing to agree to binding emissions reductions at a later date.

However, technological change can counteract the impact of diminishing returns. While the costs of additional emissions reductions *at a given time* increase as more projects are completed, the arrival of new technologies may reduce the future cost of reducing emissions. As noted earlier, the advancement of climate policies in developed countries can be expected to further lower these costs, even without emissions reduction commitments from developing countries. As these technologies become available in developing countries, the costs of emissions reductions will fall, at least partially offsetting the low-hanging fruit problem. For CDM to contribute to these falling costs, it is important that projects (a) include a component of technology transfer, and (b) that this transfer include disembodied knowledge, so that the benefits spill over into the economy as a whole. Designing CDM policy to encourage such transfers reduces the likelihood that the low-hanging fruit problem will arise.

Encouraging Technology Transfer within CDM

CDM is an important source of aid to developing countries, providing more resources than the Global Environmental Facility. However, CDM investments are small compared to private flows of FDI (Gupta et al. 2007, referencing Ellis et al. 2007). Most CDM projects have taken place in China.

In the early years of CDM trading, reducing trifluoromethane (HFC-23) emissions dominated CDM projects. HFC-23 is a powerful greenhouse gas with a global warming potential (GWP) equivalent to 11,700 tons of CO_2. HFC-23 is cheap to eliminate, and its use is already prohibited in developed countries as a result of the Montreal Protocol (*The Economist* 2007). Even in developing countries, many of these HFC-23 reductions are likely to have occurred even without the aid of developed countries. The cost of eliminating HFC-23 is so low that firms producing the gas make more money from selling CDM credits than they do by selling the gas themselves (Wara 2007). To avoid the possibility of new firms entering the HFC-23 market simply to sell CDM credits, the United Nations no longer allows CDM credits to be sold to new HFC-23 producers (*The Economist* 2008).

Projects to eliminate HFC-23 are an example of equipment transfers that may eliminate low-hanging fruit, but do not enhance the technical ability of the recipient country. As opportunities for further HFC-23 reductions are few, the focus of CDM reductions changed in 2007 to clean energy projects, such as renewable energy, fuel switching, and energy efficiency (Capoor and Ambrosi 2008), where the potential for transfer of knowledge exists, depending on how the project is set up.

While the CDM language in the Kyoto Protocol does not require technology transfer, individual host countries can take action to encourage technology transfer. CDM projects must be approved by the host country's government. Some countries choose to evaluate the technology transfer potential of projects when considering approval. For example, South Korea requires that "environmentally sound technologies and know-how shall be transferred" by CDM projects in Korea (Lee 2006, quoted in Haites et al. 2006). As a result, 88 percent of the emissions reductions from CDM projects in South Korea come from projects that involve technology transfer. Similarly, Chinese guidelines for CDM project approval state that "CDM project activities should promote the transfer of environmentally sound technology to China" (China 2005, quoted in Haites et al. 2006). While this is not mandatory, 75 percent of CDM emissions reductions in China come from projects that transfer technology.

In contrast, the percentage of reductions coming from projects with technology transfer is lower in countries that do not specifically consider technology transfer when approving CDM projects, such as Brazil or India (Haites et al. 2006).

How might policy encourage CDM projects with a technology transfer component? Dechezleprêtre et al. (2008) looked at 644 CDM projects registered by the Executive Board of the UNFCCC to determine how many projects transferred "hardware," such as equipment or machinery, as opposed to "software," that is, knowledge, skills, or know-how. In other words, how often did these CDM projects transfer knowledge and skills that not only allow a developed country investor to meet emissions reduction credits, but also enable the recipient developing country to make continual improvements to their own emission levels?

Dechezleprêtre et al. found that 43 percent of the projects (279), 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, 57 transferred equipment, 101 transferred knowledge, and 121 transferred both equipment and knowledge. The percentage of projects involving technology transfer varied depending on the type of technology used in the project. For instance, all projects reducing HFC-23 involved solely a transfer of equipment. Most projects reducing nitrous oxide and recovering methane also involved equipment transfer, as did renewable energy projects such as wind and solar. In contrast, energy efficiency measures were less likely to include technology transfer, offering another reason for viewing CDM projects promoting energy efficiency skeptically. Technology transfer also varied by recipient country. Just 12 percent of the projects studied in India included technology transfer, compared to 40 percent in Brazil and 59 percent in China.

The authors found that a project is more likely to include technology transfer if it is larger, if the project developer is a subsidiary of a company in a developed country, and if the project includes one or more carbon credit buyers. Before credits for a project can be sold, the emission reductions must be certified. Because they have an interest in obtaining emission credits, credit buyers help to facilitate this process. Similar to Lovely and Popp (2008), they also found that trade policy is important. Technology transfer is more likely if the country is more open to trade.

The technological capacity of a country also enhances technology transfer, as it makes the recipient better able to absorb new knowledge. This result is sector specific, however, and is only important in the energy and chemical industries. Interestingly, in the case of agriculture, technological capacity reduces the likelihood of technology transfer. Much R&D activity in developing countries focuses on agriculture. As such, countries with greater technological capacity are better able to develop their own innovations in agriculture, reducing the need for technology transfer from abroad.

Technology transfer is less likely if there are other similar projects in the country. These results suggest that the needs of the host country should be considered when certifying (or choosing not to certify) CDM projects. They also suggest that more general policies designed to improve absorptive capacity in a country enhance the prospects for technology transfer. Offering assistance in the development of absorptive capacity, such as training for environmental engineers in developing countries, could be a useful bargaining chip for developed countries in the next round of climate negotiations.

Conclusions

As the economies of developing countries grow, greenhouse gas emissions from these countries will continue to rise. Curtailing growth in these countries is not a viable alternative. The diffusion of clean technologies will play a vital part in any climate stabilization strategy. This study reviews the literature on transfer of environmentally-friendly technologies and discusses how the lessons from this research can inform climate policy.

A key point is that technology diffusion is gradual. The process of diffusion of climate friendly technologies and policies in developing countries is no different from what has already occurred with other environmental policies, such as for sulfur dioxide (SO_2) emissions and leaded gasoline. Early adoption of policy by developed countries leads to the development of new technologies that make it easier for developing countries to reduce pollution as well. Some technologies, such as those that enhance energy efficiency, will diffuse to developing countries even without the aid of policy prescriptions such as the CDM. This is important for assessing the potential emissions reductions of proposed CDM projects.

While often frowned upon by environmental advocates, *globalization,* that is, the opening up of economies to international competition, plays an important role in moving clean technologies to developing countries. Clean technologies are first developed in the world's leading economies, and developing countries gain access to them through international trade and foreign investments. These countries then adopt environmental regulations more quickly than they otherwise would.

Finally, the absorptive capacity of nations is important. The technological skills of the local workforce enable a country to learn from, and build upon, technologies brought in from abroad.

Design and Implementation of Future CDM Projects

- **Better understanding of the rates of diffusion**

The gradual, dynamic nature of diffusion also has important implications for the design and implementation of future CDM projects. We cannot predict which countries would still gain access to which technologies without CDM projects. We need to develop evidence and methodologies to predict whether a proposed technology would be likely to diffuse to a country during the life of a CDM project, even if the project did not take place. A recent World Bank report (2008) finds evidence that newer technologies are moving to developing countries at faster rates than in the past. However, there is little evidence on the speed of diffusion of climate-friendly technologies. As knowing the speed of diffusion is important for policy implementation, such studies are a promising topic for future research. Such a research agenda could focus on global rates of diffusion, as well as the behavior of multinational corporations in other developing countries. Intuitively, the key is to be able to determine whether the technology proposed in a CDM project application is about to diffuse to the country anyway—for example, is it already appearing in countries that are similar but only slightly more advanced? Such criteria would help ensure that CDM projects not only assist developed countries in meeting emission reduction requirements, but also aid developing countries through knowledge spillovers from technology transfer.

- **Designing CDM to encourage knowledge spillovers.**

Finally, as the world prepares for a successor to the Kyoto Protocol, an important question is whether CDM can be enhanced more generally to encourage technology transfer. The current CDM addresses the environmental externality market failure by providing investors with an opportunity to profit from climate-friendly investments in developing countries. However, CDM does not address market failures resulting from the public goods nature of knowledge (see, for example, Driesen 2008). Increased attention to the long-term development implications of CDM technology transfer would be consistent with the sustainable development goals of CDM.

Encouraging such spillovers will be challenging. Policymakers could simply choose to withhold approval for CDM projects that do not result in knowledge spillovers. However, doing so without compensating firms for these spillovers would lower the interest of developed country investors in CDM projects. While projects unlikely to contribute knowledge spillovers would be reduced, there is no guarantee that such a policy would actually increase projects with knowledge spillovers.

To increase the spillovers resulting from CDM projects, investors would need to be compensated for the benefits these spillovers provide. Traditional policies for encouraging R&D, such as intellectual property rights, are not appropriate, as they work by preventing spillovers rather than enhancing them. Instead, subsidies to CDM investors would compensate them for the positive social benefits of knowledge spillovers. Funding for such subsidies would most likely have to come from developed countries. While developed countries may balk at such aid, it would not only improve the development prospects of recipient countries, but also the likelihood that these recipient countries will agree to binding emissions reductions at a later date.

Appendix. Annex 1 Countries of the Kyoto Protocol

	Country	Annex 1	OECD
1	Australia	●	●
2	Austria	●	●
3	Belarus	●	
4	Belgium	●	●
5	Bulgaria	●	
6	Canada	●	●
7	Croatia	●	
8	Czech Republic	●	●
9	Denmark	●	●
10	Estonia	●	
11	European Community	●	
12	Finland	●	●

13	France	•	•
14	Germany	•	•
15	Greece	•	•
16	Hungary	•	•
17	Iceland	•	•
18	Ireland	•	•
19	Italy	•	•
20	Japan	•	•
21	Korea		•
22	Latvia	•	
23	Lichtenstein	•	
24	Lithuania	•	
25	Luxembourg	•	•
26	Mexico		•
27	Monaco	•	
28	Netherlands	•	•
29	New Zealand	•	•
30	Norway	•	•
31	Poland	•	•
32	Portugal	•	•
33	Romania	•	
34	Russian Federation	•	
35	Slovak Republic/Slovakia	•	•
36	Slovenia	•	
37	Spain	•	•
38	Sweden	•	•
39	Switzerland	•	•
40	Turkey	•	•
41	Ukraine	•	
42	United Kingdom	•	•
43	United States	•	•
Sources: www.OECD.org; unfccc.int (Kyoto Protocol).			

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