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POLICIES FOR THE DEVELOPMENT AND TRANSFER OF ECO-INNOVATIONS: LESSONS FROM THE LITERATURE

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Keywords: clean development mechanism, climate change, eco-innovation, environment & development, government policy, green technologies, intellectual property

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ABSTRACT

Along with the recent success of economic growth in the developing world comes more pollution. Reducing these emissions while still enabling these countries to grow requires the use of new technologies in these countries. In most cases, these technologies are first created in high-income countries. Thus, the challenge for environmental policy is to encourage the transfer of these environmentally-friendly technologies to the developing world.

This paper reviews the economic literature on both the creation and transfer of environmental technologies, with an emphasis on how the development of new technologies in leading economies can lead to environmental improvements in developing countries.

I begin by discussing the incentives for environmentally-friendly innovation, which occurs primarily in developed countries. I then review the literature on the transfer of these technologies to the developing world. A key point is that technology diffusion is gradual. 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. Globalization also plays an important role in moving clean technologies to developing countries. Since clean technologies are first developed in the world's leading economies, international trade and foreign investments provide access to these technologies. 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. I conclude by discussing the implication of these lessons for policy, focusing on three examples pertaining to climate change: the Clean Development Mechanism, the role of intellectual property, and government-sponsored R&D.

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RESUME

La croissance économique récente dans les pays en développement s'accompagne d'un accroissement de la pollution. Pour réduire ces émissions tout en se développant, ces pays devront utiliser de nouvelles technologies. Le plus souvent, ces technologies émaneront de pays développés. Ainsi, un défi des politiques environnementales est d'encourager le transfert de technologies propres vers les pays en développement.

Cet article passe en revue la littérature économique sur la création et le transfert des technologies environnementales. Il met l'accent sur les liens entre le développement de ces technologies dans les pays développés et l'amélioration de la performance environnementale des pays en développement.

Je commence par discuter les incitations à l'innovation favorable à l'environnement, qui se situe essentiellement dans les pays développés. Ensuite, j'analyse la littérature qui traite du transfert de ces technologies vers les pays en développement. Un résultat majeur est que la diffusion de ces technologies est graduelle. Lorsque les pays développés adoptent une politique environnementale, cela peut induire le développement de nouvelles technologies qui vont rendre plus facile la réduction des pollutions dans les pays en développement. La globalisation joue un rôle important dans le transfert de technologies vers les pays en développement. Dans la mesure où les technologies propres émanent d'abord des pays développés, le commerce international et les investissements internationaux donnent accès à ces technologies. Enfin, la capacité d'une économie à absorber le progrès technique est un facteur important. Les compétences technologiques de la main d'œuvre locale permettent à un pays d'apprendre et d'exploiter des technologies importées de l'étranger. En guise de conclusion, je discute les conséquences de ces résultats pour les politiques publiques, en me focalisant sur trois exemples dans le domaine de la lutte contre le changement climatique : le mécanisme de développement propre, le rôle de la propriété intellectuelle et l'aide publique à la R&D.

Codes JEL : O33, O34, O38, Q55, Q58
Mots clés : changement climatique, éco-innovation, environnement & développement, mécanisme de développement propre, politiques publiques, propriété intellectuelle, technologies propres.

FOREWORD

This paper was prepared by David Popp, for the Organisation for Economic Cooperation and Development, in September 2009.

It was commissioned in the context of the work developed by the Environment Directorate on eco-innovation. It complements other reviews and empirical investigations on similar issues which support the discussions at the Global Forum on Environment focused on eco-innovation, held on November 4-5, 2009, at the OECD Conference Center in Paris, France.

For more information visit www.oecd.org/environment/innovation/globalforum.

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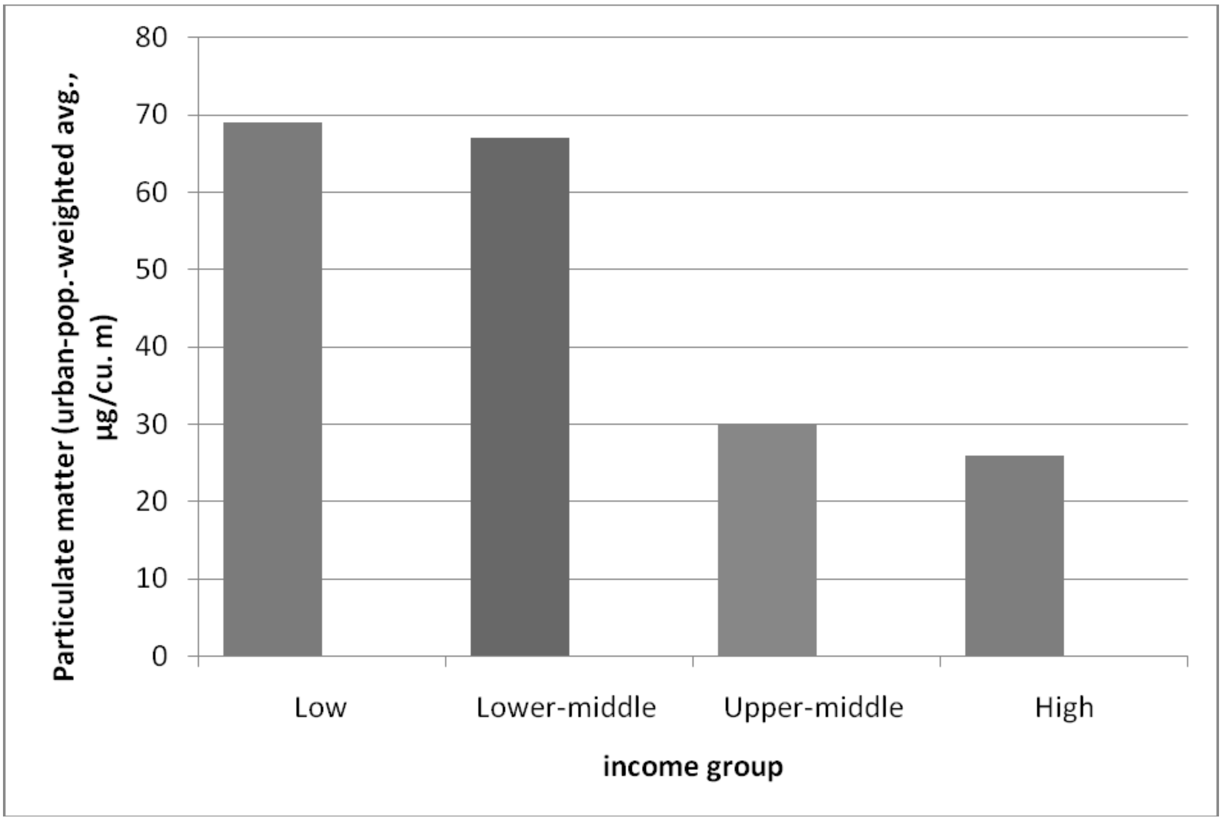
INTRODUCTION

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 often comes more pollution. For instance, a recent World Bank report shows that levels of particulate matter (PM) in urban areas are over twice as high in low and lower-middle income countries than in upper-middle and high income countries (Figure 1). As a result, these low and low-middle income countries lose an average of 0.7% of gross national income from PM-related damages, compared to just 0.3% for high income countries (World Bank, 2009).

Figure 1 – Urban Particulate Matter by Income



Technological innovation can play an important role in ameliorating these environmental impacts. One reason that upper-middle and high income countries have been able to achieve better environmental quality is through their use of advanced pollution abatement techniques.[1] Thus, technologies that could reduce emissions in developing countries exist, making the transfer of these technologies to developing countries important. Indeed, technological advances are a key component of China's overall environmental strategy, with their 2006 Report on the State of the Environment in China declaring

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[1] See, for example, Dasgupta *et al*. (2002).

scientific innovation the key to "historic transformation of environmental protection" and "leap-frog development".

Moreover, the concern is not just for the local environment in developing countries. Global environmental problems are also an issue. 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). 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.

This rapid growth in emissions from developing countries comes at a time when developed countries are beginning to reign in carbon dioxide emissions. Because carbon dioxide emissions persist in the atmosphere for hundreds of years, these countries are responsible for nearly all of the increase in carbon concentrations that has occurred since the industrial revolution.[2] Through the principle of common but differentiated responsibilities, the Kyoto Protocol placed the burden of reducing carbon emissions on those countries responsible for the initial increase in carbon concentrations. The Kyoto Protocol requires developed and transitioning countries, referred to as Annex B countries in the Protocol, to reduce their emissions of greenhouse gases by an average of 5 percent below 1990 levels by the year 2012.[3] Although the United States has not ratified the Kyoto Protocol, other Annex I countries have, and plans to reduce CO_2 emissions have been introduced in many of these nations.[4]

With negotiations for the successor to the Kyoto Protocol underway, emissions from developing countries will receive increased attention in the years ahead. Indeed, one of the primary objections of US policymakers to Kyoto is the lack of reductions from developing countries. However, forcing mandatory emissions limits on developing countries will be difficult, as these countries face pressures to develop and modernize their economies and provide a higher standard of living for their citizens. The main source of emissions is the burning of fossil fuels, an activity that increases as a country's economy grows. Anticipating this call for action, China reiterated its position that mandatory caps on developing country emissions would be unfair when it released its first national strategy for climate change in June of 2007. The centerpiece of China's strategy is energy efficiency, which China hopes to improve by 20 percent by 2010 (Yardley and Revkin, 2007).

As both economic growth and population growth are expected to lead to increased fossil fuel consumption, reducing emissions depends on one of two strategies (Holden 2006). One is to 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. A second option is to reduce energy intensity (energy usage per dollar of GDP) by improving

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[2] Atmospheric carbon concentrations rose from a pre-industrial revolution base of approximately 275 to 285 partsper million (ppm) to 379 ppm in 2005 (IPCC 2007). Most climate policy proposals call for stabilizing concentrations somewhere in the range of 450 to 550 ppm.

[3] Annex I countries include all Annex B countries except Turkey, which had not ratified the United Nations Framework Convention on Climate Change (UNFCCC) when the Kyoto Protocol was signed. These countries are Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, and the United States.

[4] Most notable among these policies is the European Union Emissions Trading Scheme (ETS). Ellerman and Buchner (2008) provide an introduction to the ETS.

energy efficiency. More efficient technologies enable a country to achieve greater economic output from a given amount of energy.

Both strategies require the continued development of new and improved technologies. 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. This question is complicated by the fact that most technological innovation currently takes place within a few highly developed economies. In 2002, global R&D expenditures were at least $813 billion. 77 percent of this R&D was done in the OECD, with 45 performed by the United States and Japan alone (National Science Board, 2008). Thus, technology transfer from developed to developing countries will be of prime importance.

This paper reviews the current literature on the development and transfer of environmentally-friendly technologies. I use the case of climate policy to discuss the implications of this research, but the lessons within apply more broadly. Perhaps the most important point is that the flow of technologies across regions is a slow, gradual process. The slow pace of action from developing countries on climate change is no different than with other pollutants, where developed countries were also the first to act. Importantly, these early actions by developed countries lead to the development of new technologies that make it easier for developing countries to reduce pollution as well. Moreover, this research shows that globalization hastens the transfer of environmentally-friendly technologies to developing countries. In some cases, such as technologies that enhance energy efficiency, these policies may diffuse to developing countries with little help from policy. In others, environmental regulation will be required to encourage the adoption of clean technologies.

TECHNOLOGICAL CHANGE AND THE ENVIRONMENT: THEORY AND EVIDENCE

Before discussing the role that policy can play to encourage the transfer of environmentally-friendly technologies to developing countries, we must first consider the incentives (or lack thereof) that firms have to develop and deploy environmental technologies. Joseph Schumpeter (1942) described the process of technological change as one of "creative destruction." 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:

- *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. These market failures provide the motivation for government policy designed to increase such research.

One market failure is the traditional problem of environmental externalities. Because pollution is not priced by the market, firms and consumers have no incentive to reduce emissions without policy intervention. Thus, without appropriate policy interventions, the market for technologies that reduce emissions will be limited, reducing incentives to develop such technologies. However, even in the absence of policy interventions, there will likely be some incentives to develop clean technologies, as private benefits may exist. For example, improving energy efficiency not only reduces emissions, but also lowers the costs of production. When consumer interest in clean products is strong, firms may choose to differentiate their products by advertising environmentally-friendly characteristics of their products. 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, by making new inventions available, some (if not all) of the knowledge embodied in the invention becomes public knowledge. This public knowledge may lead to additional innovations, or even to copies of the current innovations.[5] These knowledge *spillovers* provide benefit 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 transfers of disembodied knowledge later in this paper 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, eco-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.

Measuring Eco-Innovation

Several possible data sources exist for studying technological change and the environment. Research and development (R&D) data offer a straightforward measure of innovative activity. R&D is an input into the innovation process. Variations in environmentally-friendly R&D spending tell us the relative importance placed on eco-friendly innovation. However, as R&D is an input, measures of R&D effort do not reveal information about outcomes of the innovation process.

Patents offer an alternative measure. Patents provide a detailed record of each invention. From the bibliographic data on a patent, the researcher can learn the identity and home country of the inventor, read a description of the invention, and see references to earlier patents. Using patent data, it is possible for researchers to collect data in highly disaggregated forms. Whereas R&D data are typically available only

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[5] Intellectual property rights, such as patents, are designed to protect inventors from such copies. However, their effectiveness varies depending on the ease in which inventors may “invent around” the patent by making minor modifications to an invention. See, for example, Levin *et al.* (1987).

for specific industries or general applications,[6] patent classifications can be used to distinguish between different types of R&D at great detail, such as air pollution control devices designed to reduce NO_X emissions versus devices designed to control SO_2 emissions.[7] In addition, economists have found that patents, sorted by their date of application, provide a good indicator of R&D activity, as patent applications are usually filed early in the research process (see, for example, Griliches 1990). As a result, patent counts not only serve as a measure of innovative output, but are indicative of the level of innovative activity itself.

However, patent data also have drawbacks. While patent counts should be expected to increase as R&D activity increases, the correlation need not be exact. Variations in patent law, both across countries and across time, must be controlled for to properly interpret patent data. Furthermore, the existence of a patent does not mean that the technology has been adopted. Indeed, studies of the economic value of patents find that most patents have little commercial value, suggesting that adoption of most patented inventions is not widespread (see, for example, Lanjouw *et al.* 1998). Moreover, firms are more likely to use patents to protect new products than new processes (Levin *et* al. 1987). As such, patent data may understate changes in the nature of innovation as countries shift their environmental policy focus from end-of-the-pipe to integrated solutions leading to modified production process.[8] Despite these caveats, patent data offer several advantages when studying technological change and its effect on the environment, and have been widely used in studies of eco-innovation.[9]

In addition to R&D and patents, other options are also available to researchers. Some studies focus on the effects of innovation. For instance, Newell *et al.* (1999) demonstrate a correlation between energy prices and the energy efficiency of home appliances available for sale between 1958 and 1993. Surveys are also used, such as in Lanoie *et al.* (2007). In a survey of firms in seven OECD countries, they find that greater stringency induces a firm to perform more environmental R&D. Surveys are particularly useful in the case of process innovations, which are more difficult for the researcher to observe with secondary data. Finally, diffusion studies often make use of adoption data for specific technologies, such as in Kemp (1997).

Incentives for Eco-Innovation

Nearly all of the world's R&D is performed in the developed OECD economies, so their environmental policies usually shape the development of environmentally-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

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[6] For example, in the US, R&D data is available from 1972-1994 for air pollution control, but it is not broken down by pollutant.

[7] For example, US patent classes 423/235-423/239 pertain to control of "nitrogen or (a) nitrogenous component", and patent classes 423/242 – 423/244 and 423/569 – 423/570 pertain to control of sulfur compounds. Using patent databases, it is possible to download all patents in these classes.

[8] In some cases, process changes may be captured by patent data, particularly when third-party suppliers provide relevant equipment or materials. For an example, see Popp *et al.* (2008), which discusses process changes in pulp and paper production.

[9] Popp (2005) provides an introduction to the use of patent data for studying environmental innovation.

the other hand, are more frequently local innovations, as local conditions shape the requirements of these technologies, and are less likely to be patented elsewhere.

Dechezleprêtre *et al*. (2009) look at climate-friendly innovation using patent data for a broad range of technologies and countries. Their work includes renewable energy technologies, carbon capture and storage, and energy efficiency technologies for buildings, lighting, and cement manufacture. Their data cover the years 1978-2003, and include patents from 76 countries. Like Lanjouw and Mody, they find that most climate-friendly innovation occurs in developed countries. The US, Japan, and Germany account for two-thirds of the innovations in their sample. Emphasizing the role of policy, innovation increases after the Kyoto Protocol in all Annex 1 countries except the US and Australia, which had not ratified Kyoto.[10]

Dechezleprêtre *et al*. also find some evidence of innovation in emerging economies. As a whole, emerging economies accounted for 16.3% of climate-friendly innovations in 2003. China, South Korea, Russia, and Brazil are all among the world's top 10 inventors, ranked by the average percentage of innovations from 1998-2003 in each technology. Interestingly, the technologies most prevalent in these countries are cement manufacture, geothermal, and biomass technologies. Of these technologies, cement manufacture and geothermal innovations take place mostly on a local scale, with less than 15% of these patents appearing in multiple countries. This is consistent with the nature of these industries, which typically serve local markets and, in the case of geothermal, may face different technological needs depending upon local conditions. As in Lanjouw and Mody, technologies of wider use globally, measured by the percentage of patents that have corresponding applications in other countries, are nearly all from top economies.[11]

The types of environmental policies used matter.

Policymakers have a range of policy instruments available to regulate environmental quality. Command-and-control regulations direct a specific level of performance, such as pounds of sulfur dioxide (SO_2) emissions per million BTUs of fuel burned, or the percentage of electricity that must be generated using renewable sources. Market-based policies establish a price for emissions, either directly through the use of fees, such as a carbon tax, or indirectly through the use of permits that can be bought and sold among firms, such as in the U.S. SO_2 market or the European Union's Emission Trading Scheme for carbon. In general, market-based policies are thought to provide greater incentives for innovation, as they provide rewards for continuous improvement in environmental quality. In contrast, command-and-control policies penalize polluters who do not meet the standard, but do not reward those who do better than mandated. For instance, Popp (2003) studies U.S. innovations for SO_2 control before and after the 1990 Clean Air Act (CAA) instituted permit trading. Before this Act, new plants were required to install a flue gas desulfurization (FGD) unit capable of removing 90 percent of SO_2. As a result, the innovations that occurred before the 1990 CAA focused on reducing the cost of FGD units, rather than on improving their environmental performance. After passage of the 1990 CAA, the nature of innovation changed, with a greater focus on improving the ability of FGD units to remove SO_2 from a plant's emissions.

However, differences among policies matter, even among market-based policies. Johnstone *et al*. (forthcoming) examine the effect of different policy instruments on renewable energy innovation in 25 OECD countries. They compare price-based policies such as tax credits and feed-in tariffs[12] to quantity-

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[10] Australia has since ratified, but the data included in Dechezleprêtre *et al*. come from before Australia's ratification.

[11] Patents are only valid in the country granting the patent. An inventor must file a patent application in each country for which protection is desired. These related applications are called *patent families*. Economists use these patent families as a sign of the importance of an invention (e.g. Lanjouw and Schankerman, 2004).

[12] Feed-in tariffs, used in various European countries, guarantee renewable energy producers a minimum price for the electricity they produce.

based policies such as renewable energy mandates, and find important differences across technologies. Quantity-based policies favor development of wind energy. Of the various alternative energy technologies, wind has the lowest cost and is closest to being competitive with traditional energy sources. As such, when faced with a mandate to provide alternative energy, firms focus their innovative efforts on the technology that is closest to market. In contrast, direct investment incentives are effective in supporting innovation in solar and waste-to-energy technologies, which are further from being competitive with traditional energy technologies.

These results suggest particular challenges to policy makers who wish to encourage long-run innovation for technologies that have yet to near market competitiveness. Economists generally recommend using broad-based environmental policies, such as emission fees, and letting the market "pick winners." This leads to lower compliance costs in the short-run, as firms choose the most effective short-term strategy. However, this research suggests complications for the long-run. Because firms will focus on those technologies closest to market, market-based policy incentives do not provide as much incentive for research on longer-term needs. This suggests a trade-off: to encourage the deployment of more expensive emerging technologies that are not yet cost-effective, directed policies such as investment tax credits or technology mandates will be needed. However, this raises the costs of compliance, as firms are forced to use technologies that are not cost-effective. One possible solution here is to use broad, market-based policies to ensure short-run compliance at low costs, and use support for the research and development process to support research on emerging technologies. Thus, the focus is on continued improvement for emerging technologies, rather than on deployment of them. Section IIIC discusses issues relevant for providing public R&D support.

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

For example, while the United States was the first country to adopt strict automobile emissions standards, the majority of vehicle air emissions patents granted in the U.S. 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 U.S. and Japanese markets (Medhi 2008), and only later did the Korean government pass their own regulations requiring advanced emission controls. Finally, Popp *et al*. (2008) show that pulp and paper manufacturers respond to the demands of consumers in key export markets when adopting cleaner paper bleaching techniques.

In contrast, using patent data to study innovation on air pollution control technologies for coal-fired power plants in the U.S., Japan, and Germany, Popp (2006a) finds that inventors of air pollution control technologies for coal-fired electric power plants respond primarily to domestic regulatory incentives. 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.

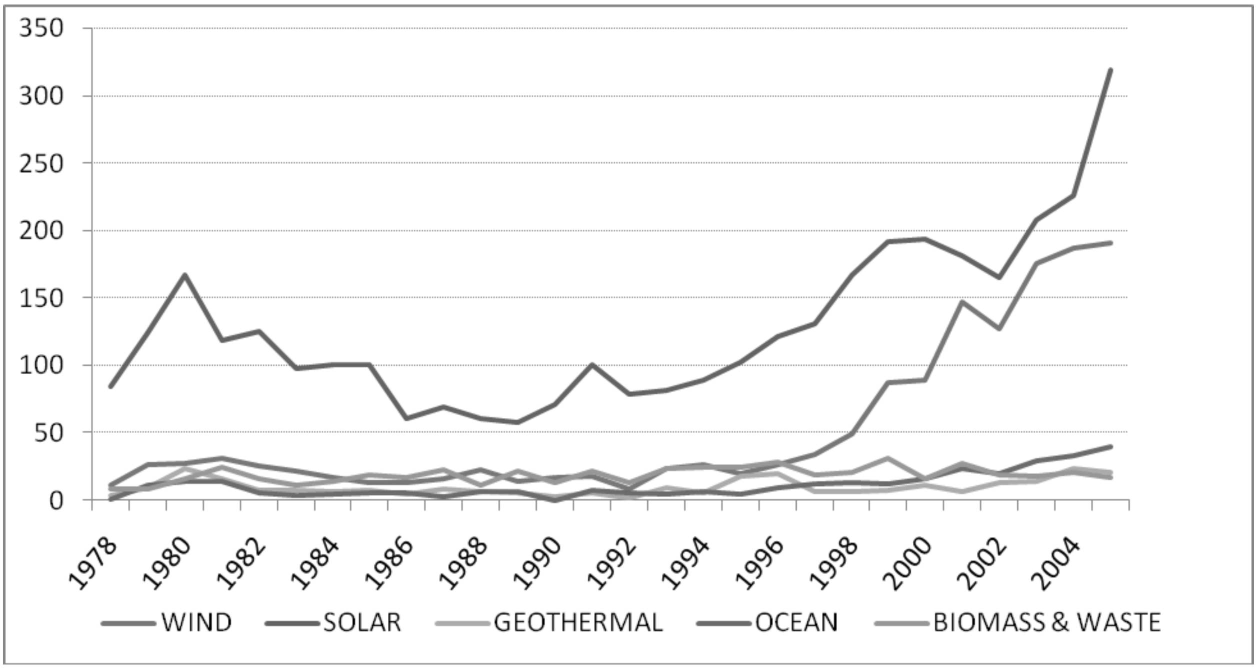
Adaptive R&D is necessary to suit the technology to the local market in developing countries.

Popp (2006a) 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 (1996) 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 environmental impacts 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 environmentally-friendly technologies.

Policies in developed countries encourage innovation of emissions-reducing technologies. Figure 2 illustrates that 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*., 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 a result, technologies to help reduce emissions in developing countries are available for adoption.

Figure 2 – 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.

TRANSFER OF ENVIRONMENTALLY-FRIENDLY TECHNOLOGIES

As innovation on environmentally-friendly technologies is already underway in developed countries, the key question for developing countries is one of technology transfer. Indeed, the availability of cleaner technologies offers developing countries to leapfrog over developed economies by adopting cleaner technologies before serious harms occur (see, for example, Dasgupta *et al*. 2002). For example, 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 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, as they relate to the spillovers discussed in the previous section. For instance, multinational corporations (MNCs) often go to great lengths to keep local workers from leaving the firm to work for a local company, in order to prevent knowledge from falling into a competitor's hands. A commonly cited example is that these corporations often pay higher wages than local firms to give workers incentives to stay.

Sources of Technology Transfer

Technology transfer may come from public or private sources. Public funding includes aid from governments or non-governmental organizations (NGO), typically in the form of official developmental assistance (ODA). Compared to private investment, ODA flows are low, but 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). GEF provides grants for developing country projects that protect the global environment. Although not devoted specifically to climate change, biodiversity and climate change are the most important of the funded categories. Since 1991, GEF has invested almost $2 billion for climate change. 90% of this funding has gone to energy efficiency, renewable energy, GHG reduction, or sustainable transportation (de Coninck *et al*. 2008).

In addition, private firms transfer technology to developing countries in three ways.

International 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, with the share of GDP attributed to imported high-tech products increasing 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 a 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. World Bank (2008) provides 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 inflows to 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 be able to earn the rewards of using the new technology (e.g. via enhanced productivity and greater profits). In other cases, local firms may be able to learn about the technology (e.g. through workers that leave the MNC to work at a locally-owned company). In such cases, spillovers occur, and the developing country's technological base is enhanced via FDI. 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 differences in technological sophistication among countries are not large (World Bank, 2008).

FDI is important for environmental technology transfer, as 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. Transfer via FDI is likely to be particularly important for integrated process solutions to reduce pollution. Although currently unexplored, this notion is a fruitful topic for future research.

License to a Local Firm

Instead of investing directly in the developing country, 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. As a percentage of developing country GDP, this represents an increase of a factor of five 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 make the MNC more willing to license technology. At the same time, these 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).

Environmentally-friendly Technology Transfer

For the transfer of environmentally-friendly technologies, it is important to consider the incentives that exist for adopting the technology. This depends 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.

Consider first emission reductions achieved using energy efficient technologies. Private firms have incentives to make such investments even without environmental policies in place, as reducing energy consumption provides cost savings to the firm. For example, Fisher-Vanden *et al.* (2006) provide evidence of energy-saving technological change in China. Studying energy consumption at 22,000 Chinese large and medium enterprises, Fisher-Vanden *et al* find that total energy use fell by 17% between 1997 and 1999. 54% of this decline can be explained by price changes. Technological change, measured by firm-level R&D, accounts for 17% of this change, and changes in ownership account for another 12%. They also find 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) studies 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% less energy than ingot casting. Fisher-Vanden finds that while centrally managed firms are the first to acquire new technology, locally managed firms complete 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. Indeed, since 1980, energy intensity, defined as energy consumption per dollar of GDP, has fallen at a rate of nearly 4% per year in China. Worldwide, energy intensity has fallen at a rate of 1.5% per year since 1995.[13] However, without policies limiting 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 include emission control devices placed on a smokestack and filters for effluent in wastewater. For climate change, examples of such technologies include clean energy sources

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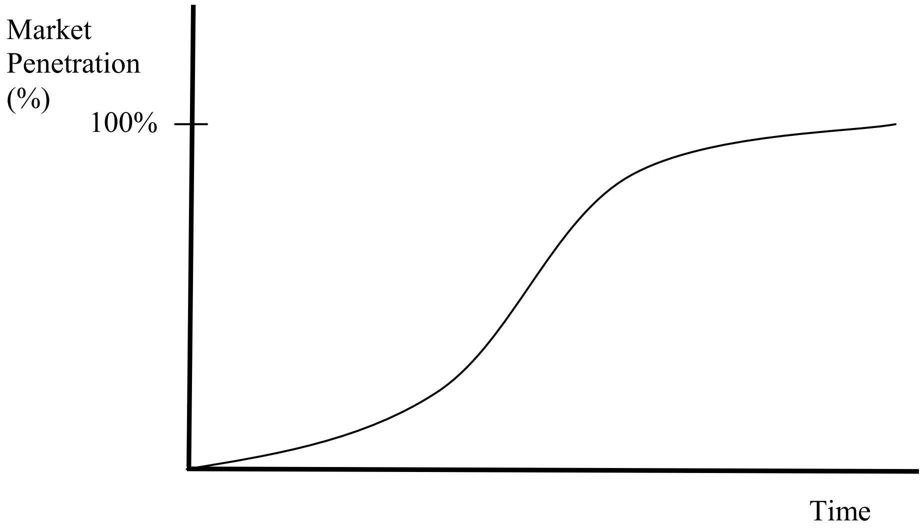
[13] Both figures are calculated from data available at http://www.eia.doe.gov/emeu/international/energyconsumption.html, accessed June 4, 2008.

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 on the effect of these polices on technology diffusion exists. However, examples of the diffusion of other air pollution technologies are available. For instance, since regulations limiting particulate matter were enacted several years before regulations covering sulfur dioxide 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 transfer environmental technology to China, but it is not advanced. In most cases, emissions control technologies used on autos in China comply with Euro II standards, which are required for Beijing and Shanghai, but would not meet developed country standards. She 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" (Gallagher, 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 (Figure 3). A period of slower adoption by the remaining stragglers follows.

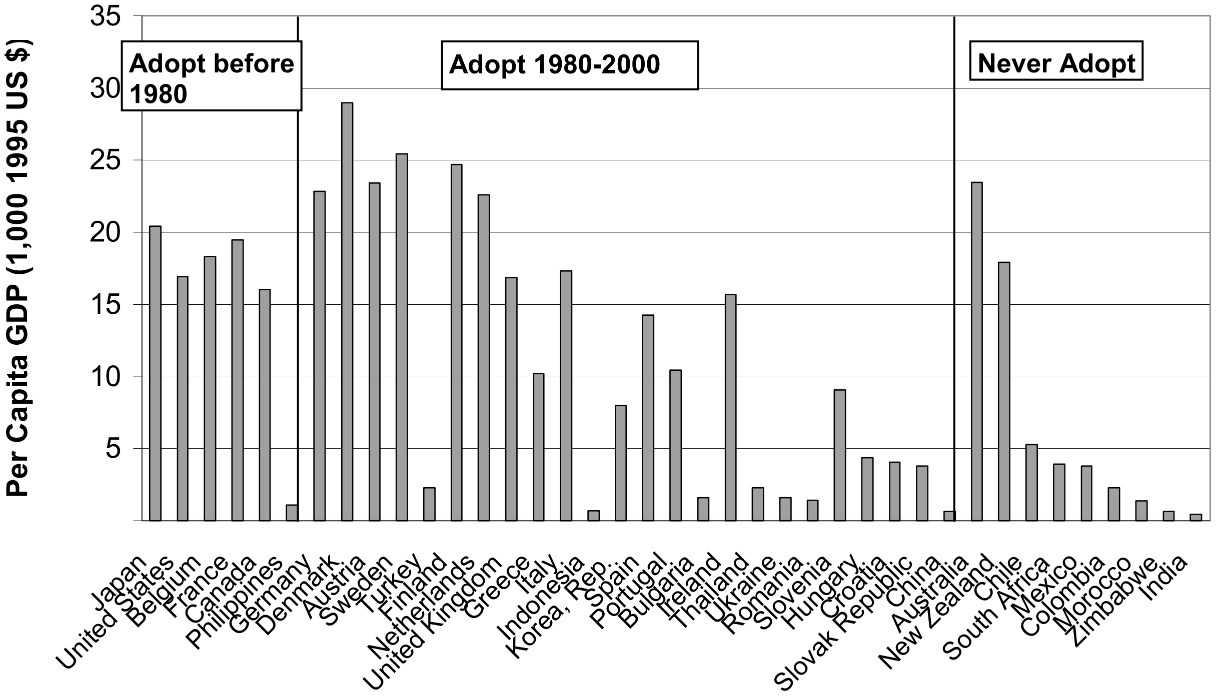
Figure 3 – S-shaped Diffusion Curve



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) study the adoption of regulations limiting emissions of sulfur dioxide and nitrogen oxides at coal-fired power plants in 39 developed and developing countries. Their study concentrates 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 4 illustrates this trend for the adoption of SO_2 emission regulations. The figure shows per capita GDP, 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 *x*-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 adopt before 1980, the first year of data in their analysis. With the exception of the Philippines, each of these countries adopts at a per capita income roughly between \$15,000 and \$20,000.[14]

Figure 4 – Per Capita GDP in the Year of Adoption: SO2



The figure, taken from Lovely and Popp (2008), shows the per capita GDP (in constant 1995 U.S. dollars) of each country in the year in which it adopts SO_2 regulations for coal-fired power plants. Countries are sorted from left to right along the *x*-axis by the order in which regulations were enacted. The first two countries, Japan and the U.S., enacted regulations in 1970. Three groups are presented. The first six countries adopted regulations before 1980, and are thus not included in Lovely and Popp's (2008) data set. The last eight countries never adopt regulation. With the exception of Australia and New Zealand, who have stocks of relatively clean coal, these are all low income countries. The remaining countries adopt between 1980-2000.

Of the countries adopting SO2 regulations between 1980-2000, there is a strong trend of countries adopting at lower incomes over time. Lovely and Popp interpret this trend as showing how the availability of technologies, produced by countries that first chose to adopt SO2 regulations, lowered adoption costs sufficiently for more countries to be able to afford reducing SO2 emissions. Moreover, they find countries that are more open to international trade gain access to new abatement technologies sooner, and thus are able to regulate SO2 emissions sooner. Finally, the third segment of Figure 4 includes countries that have

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[14] Early adoption of regulation in the Philippines is explained by close bilateral relations with the United States, which includes aid for environmental protection.

yet to adopt SO2 regulations. Except for Australia and New Zealand, who choose to not regulate SO2 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 finds that late adopters of regulation can learn from early adopters. Using data on 48 nations, he looks at the time it took each country to eliminate lead from fuel, measuring from the time that each country first began phasing out lead in fuel to the time in 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 those countries that did not completely phase out lead, countries that begin the phase-out process earlier achieve greater reductions. Hilton concludes with evidence that late adopters are able to move more quickly because they benefit from lessons learnt by early adopters.

Both these studies suggest that developed country advances in technology can hasten the time at 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.

POLICY IMPLICATIONS – THE CASE OF CLIMATE CHANGE

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 needs for continued development, developing countries are unlikely to enact policies requiring binding emissions reductions at this time. 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 emission 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 CO2 emissions as they did in the cases of SO_2, NO_X, and lead.[15] 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.

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[15] One might also consider how related regulations affect CO_2 emissions. Here, one can imagine two possibilities. Consider, for instance, the rapid construction of coal-fired power plants in China. Future air quality regulations may raise the costs of operating these plants, making investments in coal power less attractive, much as natural gas plants in the U.S. became more attractive as environmental regulations raised the costs of using coal. However, these regulations may also make the construction of new coal plants more acceptable to the general public. By mandating that new plants use advanced environmental technologies to reduce air pollution, newer plants emit fewer pollutants and are less offensive to the neighboring population. Which of these effects dominate is a question open to further study.

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*. Golombek and Hoel (2004) note that, in the countries committed to carbon reductions, induced technological change will lower abatement costs. In some cases, these cost reductions will be sufficient to encourage non-participating countries to reduce carbon emissions as well. Golombek and Hoel find 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 policy makers better understand the risks (or lack thereof) of incomplete participation.

The Clean Development Mechanism

Currently, incentives for climate-friendly technology flows come from the Clean Development Mechanism (CDM), which allows developed country actors to meet emissions reduction limits by sponsoring projects in developing countries. The Clean Development Mechanism allows polluters in Annex B countries with emission constraints to receive credit for financing projects that reduce emissions in developing countries that do not face emission constraints under the Kyoto Protocol.[16] 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. The use of CDM projects by developed countries has grown in recent years, as the binding commitments of the Kyoto Protocol begin to take effect. As would be expected, most buyers are European, given the EU's active role reducing CO_2 emissions. European countries sponsored 87% of CDM and Joint Implementation projects, with Japan accounting for another 11%.[17]

CDM provides the regulatory incentive to undertake emissions reducing activities in developing countries that don't provide the user private costs savings, such as lower energy costs. The capturing of landfill gas is an example of an emissions mitigation project that would not occur without regulation. It 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 are not rewarded for the environmental benefits of reduced carbon emissions resulting from lower energy consumption. Included as part of the Kyoto Protocol, the Clean Development Mechanism allows developed countries to meet emissions reductions obligations by sponsoring projects in developing countries.

Among the goals for CDM stated in the Protocol is that CDM should help developing countries achieve sustainable development (Kyoto Protocol, Article 12.2, 1997). Whether or not CDM is successful in this goal depends, in large part, on its ability to transfer technologies. By transferring technology to the host country, the Clean Development Mechanism can play a role in lowering 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.

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[16] Lecocq and Ambrosi (2007) provide a description of the Clean Development Mechanism.

[17] Joint implementation projects are similar to CDM projects, except that the project takes place in another Annex B country.

While language in the Kyoto Protocol does encourage the transfer of climate-friendly technologies, the Clean Development Mechanism was not explicitly designed with the goal of technology transfer in mind. Although CDM addresses the environmental externality market failure discussed in section I, by providing investors an opportunity to profit from climate-friendly investments in developing countries, it does not explicitly address market failures resulting from the public goods nature of knowledge (see, for example, Driesen, 2008). 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.

Related to technology transfer is a concern often raised by critics of CDM – the problem of "low-hanging fruit."[18] The low-hanging fruit critique follows from the economic principle of diminishing returns. This can be illustrated by the example of trying to reduce energy consumption in your own home. The first steps that a home owner can take are straightforward and virtually costless – turning off lights when not in use, lowering the thermostat, and installing compact fluorescent light bulbs are examples. After taking these steps, achieving additional reductions in energy consumption would entail larger costs, such as replacing older appliances with newer energy efficient models and adding additional insulation. Similarly, when considering emission reductions in a country, we expect that the easiest, least expensive projects will be done first. To the extent that CDM projects do not involve technology transfer, but rather a developed country investor acting unilaterally, these low cost options will be used up, making future emission reductions more costly. 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.[19]

Technological change 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. As noted in Section II, the advancement of climate policies in developed countries can be expected to lead 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 help 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 spillover into the economy as a whole.

Designing CDM policy in a way to encourage such transfers reduces the likelihood that the low-hanging fruit problem will arise. For instance, 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 CO2. 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

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

[19] 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.

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).

While the CDM language in the Kyoto Protocol does not require technology transfer, individual host countries can take action to encourage technology transfer from projects in their country. 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. 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, Art. 10, p.2, quoted in Haites *et al*. 2006). While this is not mandatory, 75% of CDM emissions reductions in China come from projects that transfer technology. In contrast, in countries that do not specifically consider technology transfer when approving CDM projects, such as Brazil or India, the percentage of reductions coming from projects with technology transfer is lower (Haites *et al*. 2006).

To better understand how policy might encourage CDM projects with a technology transfer component, consider the results of Dechezleprêtre *et al*. (2008). 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?

Dechezleprêtre *et al*. 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, 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 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, offering another reason for viewing CDM projects promoting energy efficiency skeptically. 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.

To assess why technology transfer varies by project, the authors of this study include a statistical model predicting the likelihood that a specific project will include a technology transfer component. 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 find that trade policy is also important. Technology transfer is more likely if the country is more open to trade. The technological capacity of a country 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. Subsidies that compensate investors for the benefits spillovers provide could also help encourage technology transfer from CDM programs. Traditional policies for encouraging R&D, such as intellectual property rights, are not appropriate, as they work by preventing spillovers, rather than enhancing them. Rather, subsidies to CDM investors could be used to compensate them for the positive social benefits of knowledge spillovers. Funding for such subsidies would most likely come from developed countries. While developed countries may balk at such aid, providing assistance to increase the prevalence of knowledge spillovers from CDM projects not only improves the development prospects of recipient countries, but also the likelihood that these recipient countries will agree to binding emissions reductions at a later date.

The Role of Intellectual Property Rights

Because of the international nature of the climate problem, technology transfer solutions often lead to proposals for international cooperation (see de Coninck *et al.* 2008 for a summary). One particular concern has been the role of intellectual property rights. There is rising interest in broader sharing of intellectual property pertaining to environmental technologies. In 2008, the World Business Council for Sustainable Development (WBCSD) created the Eco-Patent Commons to allow free access to patents with environmental benefits. In a 2009 interview, Steven Chu, the U.S. Secretary of Energy, encouraged the sharing of intellectual property, stating that “any area like that (energy efficient buildings), I think, is where we should work very hard in a very collaborative way — by very collaborative I mean share all intellectual property as much as possible.”[20]

Intellectual property rights (IPR) provide a tradeoff to both inventors and to society as a whole. The goal of IPR is to reward inventors for the fixed costs of innovation. For eco-innovations, patents are the relevant form of IPR. Successful patent applicants are provided a temporary monopoly, lasting twenty years from the initial application date, in return for disclosing information on the innovation in the patent document, which is part of the public record. By granting this market power, IPR helps to mitigate potential losses from knowledge spillovers and encourage innovation. Thus, it is certainly true that, *conditional on an innovation having taken place*, one would expect technology transfer to be slower when IPR is in place. However, one cannot assume that the level of innovation would be the same if IPR were not available.

To date, there has been little work directly studying the effect of intellectual property rights on technology transfer of eco-innovations. One exception is a study done by Copenhagen Economics (2009). Focusing on climate change, this study concludes that IPR are not a barrier to the transfer of carbon emission-reducing technologies, and that the high costs of these technologies are due more to the immaturity of the technologies, rather than IPR.

While there is still room for more research on the question of IPR and eco-innovation, the conclusions of the Copenhagen Economics report are consistent with findings in other technological areas. For instance, Branstetter *et al.* (2005) find that stronger IPR increases technology transfer among U.S. multinationals, and Smith (1999) provides evidence that weak IPR are a barrier to U.S. exports in countries

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[20] http://dotearth.blogs.nytimes.com/2009/03/26/energy-chief-seeks-global-flow-of-ideas/#more-1775, accessed July 2, 2009.

where imitation is likely, such as China. Finally, in an oft-cited study on the role of intellectual property on pharmaceuticals, Attaran and Gillespie-White (2001) ask whether patents constrain access to AIDS treatments in Africa. They find that, even in African countries where patent protection is possible, few AIDS drugs are patented. They conclude that a lack of income, national regulatory requirements, and insufficient international aid are the main barriers to the spread of AIDS treatments in Africa. Similarly, with eco-innovations, one would expect demand (or the lack thereof) for clean technologies to be a primary constraint on international technology transfer. As noted in section II, the spread of environmental regulation across developing countries is an important pre-condition to the diffusion of eco-innovations. Calls to weaken IPR for eco-innovations will have little impact unless they are packaged in international agreements leading to stronger environmental regulation within the developing world.

The Role of Government – Incentives for Long-term R&D

One of the particular problems faced with many eco-innovations is the long-time frame from the initial invention to successful market deployment. Consider, for instance, the case of solar energy. Despite research efforts that began during the energy crises of the 1970s, solar is still only cost competitive in niche markets, such as remote off-grid locations. Until now, I have focused primarily on the incentives faced, and activities conducted, by private firms. As noted in section I, even when environmental regulations that encourage eco-innovation are in place, private firms will focus research efforts on technologies that are closest to market. This leaves a role for government-sponsored R&D to fill in the gaps, particularly in the case of climate change, where a diversified energy portfolio will be necessary to meet currently proposed emission reduction targets.

Government R&D can help to compensate for underinvestment by private firms. Unlike firms, the government is in position to consider social returns when making investment decisions. In addition, government R&D tends to have different objectives than private R&D. Government support is particularly important for basic R&D, as long-term payoffs, greater uncertainty, and the lack of a finished product at the end all make it difficult for private firms to appropriate the returns of basic R&D. Thus, the nature of government R&D is important. For example, Popp (2002) finds that government energy R&D served as a substitute for private energy R&D during the 1970s, but as a complement to private energy R&D afterwards. One explanation given for the change in impact is the changing nature of energy R&D. During the 1970s, much government R&D funding went to applied projects such as the effort to produce synfuels. Beginning with the Reagan administration, government R&D shifted towards a focus on more basic applications. To avoid duplicating, and potentially crowding-out, private research efforts, government R&D support should focus on basic research or on applied research whose benefits are difficult to capture through market activity. For instance, improved electricity transmission systems benefit all technologies, and will typically not reap great rewards for the innovator. Applied technologies whose costs are still high, such as solar photovoltaics, will also see less private investment, as firms focus on projects with greater short-term payoffs. In cases such as these, public R&D efforts will be important.

The uncertain nature of long-term research also makes government R&D valuable. In a situation where failure is more likely than success, but the successes will have great social value, government can bear the costs of a diversified R&D portfolio more easily than any one private firm. Consider, for example, the U.S. National Research Council's review of energy efficiency and fossil energy research at Department of Energy (DOE) over the last two decades (National Research Council 2001). Using both estimates of overall return and case studies, they concluded that there were only a handful of programs that proved highly valuable. Their estimates of returns suggest, however, that the benefits of these successes justified the overall portfolio investment. These uncertain returns also suggest that government research portfolios should be diversified, rather than trying to pick winning technologies at early stages of development.

In addition to correcting for underinvestment by private firms, many government R&D projects aim to improve commercialization of new technologies (referred to as "transfer" from basic to applied research). These efforts can help move projects from the basic research stage to commercialization, a stage of development that has become known as the "valley of death" within the alternative energy field. Such projects typically combine basic and applied research, and are often done through government/industry partnerships (National Science Board, 2006). For example, the United States passed several policies in the 1980s specifically designed to improve transfer from the more basic research done at government and university laboratories to the applied research done by industry to create marketable products.[21] As such, this technology transfer can be seen as a step between the processes of invention and innovation. In a study focused on energy R&D, Popp (2006b) examines citations made to patents in 11 energy technology categories, such as wind and solar energy. He finds that energy patents spawned by government R&D are cited more frequently than other energy patents. This is consistent with the notion that these patents are more basic. More importantly, after passage of the technology transfer acts in the early 1980s, the children of these patents (that is, privately-held patents that cite government patents) are the most frequently cited patents, suggesting that transferring research results from the government to private industry produces valuable research results.

Finally, an important question for policy makers is how much government R&D money to spend on energy. Here, however, economics provides less of an answer. Engineers are better suited to determine which projects are most deserving from a technical standpoint. Given the need for a diversified energy portfolio to address climate change, it is hard to imagine that there would not be enough deserving technologies for the research funding available. What economics suggest is that the constraints for funding are likely to come from other sources, such as what is the pool of scientist and engineering (S&E) personnel currently available to work on energy projects, and how quickly can we grow this pool. That is, the limits to how much we can spend come not from the number of deserving projects, but rather limits of the existing research infrastructure.

As an example, consider the experience of the U.S. National Institutes of Health (NIH), which supports biomedical research in the U.S. The NIH budget has traditionally grown at a slow, steady pace. However, between 1998-2003, annual NIH spending nearly doubled, from $14 billion to $27 billion. Adjusted for inflation, this represents a 76% in just five years, and was nearly twice as high as the increase for the entire decade before. This rapid increase resulted in high adjustment costs. New post-doctorate researchers needed to be brought in to support research projects. Managing a larger budget entails administrative costs for NIH. Moreover, after this rapid doubling, research funds were cut, so that real NIH spending was 6.6% lower in 2007 than in 2004. This created a career crisis for the same post-doctorate researchers supported by the earlier doubling of support, as there was more competition for funds to start their own research projects. Moreover, scientists spent more time writing grant proposals. Because the probability of funding for any one proposal falls as the NIH budget falls, researchers submitted multiple proposals in the hope that one would succeed (Freeman and van Reenen, 2009). This NIH experience suggests that growth in energy R&D budgets should be slow and steady, allowing time for the development of young researchers in the field. Such considerations are particularly important given the current macroeconomic environment, in which green investments are considered an engine for recovery.

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[21] Examples include the Stevenson-Wylder Technology Innovation Act of 1980, the Bayh-Dole Act of 1980, and the Federal Technology Transfer Act of 1986.

CONCLUSIONS

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

Regarding innovation, we see that incentives matter. Environmental policies must be in place to encourage the development of clean technologies. However, as the bulk of R&D occurs in developed countries, it is their policies that shape the direction of environmental innovation. Moreover, the types of policies matter. Broad-based market policies foster more innovation, but private firms will focus innovation on those technologies closest to market. Thus, public R&D support will also play a role.

Regarding the transfer of environmentally-friendly innovations, perhaps the most important lesson from research on technology diffusion is that diffusion is gradual. While developed country politicians complain that the lack of binding commitments from developing countries gives these countries an unfair advantage, the process of diffusion of climate friendly technologies and policies is no different than what has occurred with other environmental policies, such as for SO_2 emissions and leaded gasoline. Moreover, evidence suggests that some technologies, particularly those enhancing energy efficiency, will diffuse to developing countries even without the aid of programs such as the CDM. There is less evidence on the time that it will take these technologies to arrive. 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 environmentally-friendly technologies. As knowing the speed of diffusion is important for policy implementation, such studies are a promising topic for future research.

Another key finding is that globalization, while often frowned upon by environmental advocates, plays an important role in moving clean technologies to developing countries. Since clean technologies are first developed in the world’s leading economies, international trade and foreign investments provide access to these technologies. Research suggests that developing countries more open to international trade adopt environmental regulations more quickly, thanks to this earlier access of clean technologies, and that CDM projects are more likely to include a technology transfer component in open economies. 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. While beyond the scope of this policy brief, more general policies that enhance these skills are an important part of fostering any type of technology transfer.

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