

Greening Global Value Chains

Innovation and the International Diffusion of Technologies and Knowledge

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Abstract

Using novel data on patents, trade of equipment goods, and foreign direct investments and insights from the economic literature, the paper seeks to lay out the state of knowledge on the role of innovation and the diffusion of technologies in the greening of global value chains as well as some of the main policy issues. A special emphasis is put on developing countries—distinguishing emerging economies and least-developed countries—and on climate-mitigation technologies. Emerging economies are already reasonably well integrated in the global economy. As a consequence, technologies flow in through the imports of capital goods and local investments by multinational enterprises owning technologies. Pushing further technology transfer requires strengthening intellectual property rights, lowering barriers to trade

and investments and improving technological absorptive capacities. In contrast, their role in innovation is limited. Standard tools of innovation policy - public research and development, public support to private research and development, better access to finance - should develop. But studies also suggest that governments should introduce more stringent environmental policies with proper enforcement at home to go beyond the adoption of foreign technologies. The situation of least-developed countries is very different: they do not import green technologies and low barriers to trade and foreign direct investment or strict intellectual property rights are unlikely to trigger technology transfer. In these countries, the focus should be on building technological capacities.

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Greening Global Value Chains: Innovation and the International Diffusion of Technologies and Knowledge

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Introduction

The objective of the paper is to lay out the state of knowledge on the role of innovation and the diffusion of technologies in the greening of global value chains as well as some of the main policy issues and key research gaps³. A special emphasis will be put on developing countries in which innovation, skills and technological absorptive capacities tend to be lower while green technologies are urgently needed. The structure of the paper is extremely simple. In the first part, we give some concepts and definitions on technology, innovation, and the channels of technology diffusion. In the second part, we use various statistics (green patents, trade flows, and foreign direct investments) and illustrative examples to describe how technology and knowledge are created today and disseminated across countries. For data reasons, we mostly focus on climate-mitigation technologies, but there are good reasons to think that other green technologies do not significantly differ from the “average” climate mitigation technology. Then, we list and discuss key policy challenges (the role of environmental policies, intellectual property rights, capacity building, etc.). The conclusion summarizes the main lessons.

The so-called “green economy” does not consist in the creation of a new economy, but mostly, in the gradual greening of existing traditional economic activities. The concept of green technology is extremely vast as this refers to the use of technology that makes traditional products and processes more environmentally friendly, for example, by reducing CO2 emissions, by making products more biodegradable, etc. In practice, many green technologies are cleaner variants of standard technologies. It follows that most of the mechanisms and trends discussed below are not specific to green technology. This is good news as we can rely on many results from a well-developed general literature on the interactions between globalization and technology.

1 Concepts and Definitions

1.1 Technology Is Information

From an economic perspective, technology consists in the application of information either *tacit* (know-how, skills) or *coded* (drawings, models, chemical formulas) in the design, production, and utilization of goods and services. In contrast with science, the creation of new technology is primarily a business matter. As an illustration, the share of climate-related patents – protecting technologies aiming at reducing greenhouse gas emissions – filed by public bodies is on average less than 10 percent in most countries.⁴

Contrary to standard tangible goods, technology and knowledge production and dissemination inevitably involve a public policy dimension. The fundamental reason is that information has public good properties: it is *non-rival* in use - information is not exhausted after its use by the innovator – and

³ The paper is partly derived from a study recently commissioned by the French Council of Strategic Analysis (2013) which deals with the specific case the international diffusion of climate-friendly technologies (Glachant, Dussaux, Ménière and Dechezleprêtre, 2013). The author also thanks Nick Johnstone, Giuseppe Nicoletti, Annabelle Mourougane for their helpful comments. The usual disclaimer applies.

⁴ China, with more than 40 percent, and France and Korea around 15 percent constitutes three exceptions. In *L’innovation technologique face au changement climatique: quelle est la position de la France ?* Yann Ménière, Fabrice Carrère, Antoine Dechezleprêtre, Matthieu Glachant, Gilles Le Blanc, Cécile Pot.

(partly) *non excludable* – restricting access to information is difficult. As a result, technology can be imitated. This is a major obstacle to its production by the market. Indeed, the development of an invention usually requires a (potentially large) upfront investment, which an inventor may be reluctant to incur if others, in particular competitors, appropriate a part of the value of the innovation.

Diffusion is a crucial, but tricky stage in the innovative process: It is when the technology is used, and thus when it yields benefits in the field. But it is also when others can imitate the technology, hindering inventors from exploiting their technology so as to benefit from market exclusivity. Any public policy should thus find ways to boost diffusion while preserving incentives to innovate. We consider in detail in Section 3 the potential of different policy instruments such as R&D subsidies, or patent law.

Learning-by-searching versus learning-by-doing

Technologies are obviously created within specialized R&D departments or organizations (learning-by-searching), but also through learning-by-doing which refers to the capability of workers to improve their productivity by regularly repeating the same type of action. The increased productivity is achieved through practice, self-perfection and minor innovations. Learning-by-doing potentially yields very large efficiency gains. The learning rate is for instance about 20 percent for photovoltaic energy technologies in the studies surveyed by De La Tour et al. (2013), meaning that (unit) costs fall by 20 percent for each doubling of cumulative production. The existence of learning-by-doing has crucial policy implications as it means that public policies should not only target R&D activities, but also downstream activities of the innovation process (experimentation, technology deployment, and commercialization). It is a form of knowledge creation which seems easier to reach for certain developing countries, which have less advanced technology capabilities.

The channels of technology transfer

The notion of “technology transfer” can be confusing, for these transfers may concern either intangible knowledge as such, or the physical support in which this knowledge is embedded. The economic literature⁵ argues that technology and the related knowledge may be transferred through voluntary transactions aiming at commercializing and/or exploiting technological products in the recipient country. Three market channels are usually distinguished (see Table 1 and Popp, 2009).

International trade in intermediate goods. The import of capital goods, such as machines and equipment, entails technology transfer for such goods embody technologies which can then bring productivity benefits in the recipient countries. International trade induces however little cross-border transfer of knowledge as such, simply because this knowledge remains in the originating country and is directly exploited there. Yet even in this case, there may be knowledge spillovers in the recipient country (Rivera-Batiz and Romer, 1991). Local firms can indeed reverse-engineer imported products, or acquire knowledge through business relationships (e.g., as customer or distributor) with the source company. As an illustration, China has acquired production technologies to develop a highly performing solar photovoltaic industry by purchasing turnkey production lines from German, US and Japanese suppliers (de la Tour et al., 2011). They are now able to produce production equipment on their own.

⁵ Keller (2004) is a comprehensive survey of the economic literature on technology diffusion.

Foreign direct investments (including joint ventures). Several studies find evidence that multinational enterprises transfer firm-specific technology to their foreign affiliates or partners in joint-ventures (e.g., Lee and Mansfield, 1996; Branstetter et al., 2006). FDI induce more knowledge transfer than trade in goods, for it aims at exploiting it directly in a local subsidiary of the source company or in a joint-venture – and not in the source country anymore. The transfer is particularly important with joint-ventures as the local partner has direct access to the technology. FDI might also generate local spillovers through labor turnover if local employees of the subsidiary move to domestic firms. Local firms may also increase their productivity by observing nearby foreign firms or becoming their suppliers or customers. Overall, the literature finds strong evidence that FDI is an important channel for technology diffusion. This is for example the key vector of technology transfer in the wind industry (Kirkegaard et al., 2009).

Licensing. The third channel of technology diffusion—and the most direct—is when corporations or public research bodies grant a patent license to a company abroad that uses it to upgrade its own production (by extension, a copyright or a brand). That is, a firm may license its technology. The very purpose of licensing is finally to carry out a full knowledge transfer to the licensor so as to enable it to exploit it directly. Accordingly, knowledge leaves both the source country and the source company, and lay now in the hands of a local third party. In practice, international licensing mostly concerns three sectors: chemicals and drugs, and electronics and electrical equipment.

This description of the channels yields a fundamental message: Encouraging economic globalization is the fundamental approach to promote the international diffusion of knowledge and technologies through the development of international trade, FDI, and the international circulation of skilled individuals.

Table 1 : Knowledge location and mechanisms of internal diffusion in the different transfer channels (Glachant et al., 2013)

Transfer channels	Knowledge location		Diffusion mechanism in the recipient country
	Geographical	Legal	
Export of equipment goods	Source country	Source company	Reverse engineering
Foreign direct investment	Recipient country	Source company	Reverse engineering + labor circulation
Joint-venture	Recipient country	Joint-venture	Reverse engineering + labor circulation + local partner opportunism
Licensing	Recipient country	Customer	Reverse engineering + labor circulation + customer opportunism

Innovating locally or adopting imported technologies?

Do technology imports substitute domestic innovation in developing countries? Responding to that question is crucial for, if affirmative, discouraging diffusion might be a way to provide local inventors with higher incentives to develop technologies at home. In fact, innovation and technology diffusion rather tend to complement each other. Deploying a technology developed abroad frequently requires skills and knowledge which are partly the same as those used for innovation. Accordingly, adopting

foreign technologies boosts innovation at home and conversely. As an illustration, China is both the top inventor and the top technology importer emerging economy for climate-mitigation technologies (as we will see below in Tables 2 and 3). In fact both strategies improve so-called technological absorptive capacities.

2 Innovation and International Technology Diffusion toward the Developing World: Available Evidence

2.1 Innovation through Learning by Searching

As indicated above, innovation comes through two mechanisms: learning by searching and learning by doing. Patent counts offer an indicator to measure the output of the former⁶. They have been used extensively in recent studies which clearly show that learning-by-searching remains mostly located in the industrialized world. As an illustration, Table 2 shows the share of climate patented inventions by country. China is the only emerging economy in the Top 10. Other major emerging economies or transition countries such as India, Russia or Brazil account for less than 1% of world innovation. Other studies dealing with waste or green chemistry confirm the stylized facts.⁷

Table 2: Top ten inventor countries in climate innovation and selected emerging economies

Rank	Country	Share of world climate patented inventions (2007-2009)*
1	USA	19.0%
2	Germany	18.7%
3	Japan	17.5%
4	South Korea	5.6%
5	France	4.8%
6	UK	3.6%
7	Italy	3.4%
8	Canada	2.7%
9	China	1.7%
10	The Netherlands	1.6%
Total top 10		78.6%
18	Taiwan, China	0.9%
21	India	0.7%
22	Russia	0.5%
25	Brazil	0.4%
31	South Africa	0.2%

Source: Glachant et al. (2013) based on PATSTAT data. * International patents refer here to claimed priorities invented in the country as a share of world claimed priorities. Mean of 25 climate technology shares.

⁶ The proxy is however imperfect for various reasons: First, patents are only one of the means of protecting inventions, along with lead time, industrial secrecy, or purposely complex specifications. Second, the propensity to patent differs between sectors, depending on the nature of the technology. Last, the value of individual patents is heterogeneous. Counting international patent families – inventions that have been patented in at least countries – partly mitigates this problem. For an extensive discussion of these limitations, see Johnstone et al. (2011).

⁷ OECD (2011), *Invention and Transfer of Environmental Technologies*, Paris, OECD.

2.2 The Diffusion of Technologies toward the Developing World

It is also possible to rely on patent statistics to measure the flows of technologies across countries. In particular, the count of patent applications in a given country for technologies invented abroad is an indicator of the volume of imported technologies. Because international trade and FDI are major channels for the transmission of technology knowledge across countries, the inflow of intermediate goods or FDI is also a possible proxy.

Table 3 relies on these three indicators to measure the climate technologies imported in selected emerging economies. It shows seemingly limited flows except towards China which represents between 7 and 15% of the world imports of technologies, depending on the indicator used. But the figures are actually not that low. To begin with, they are much higher than the percentages given in the previous table dealing with innovation. Moreover, they are more or less in line with each country's economy size as measured by the GDP. Two exceptions are Russia and India which account for 3.3% and 4.9% of the world GDP whereas, depending in the indicators used, the size of inward transfers represents between 1.3 and 2.2% for the former and about 1.5% for the latter.

All in all, contrary to innovation, emerging economies appear to participate, albeit to varying degrees, in the global exchange of climate-friendly technologies, simply because they are key actors of the economic globalization. Note that the diffusion of climate-mitigation patented technologies is higher than that of non-green ones, but international trade is lower (in Table 3, see statistics in parentheses). This probably reflects different time horizons: international trade is driven by the current demand for green technologies, which is quite low in developing countries where environmental and climate policies are less advanced. Patenting is driven by the demand which is expected in the next 20 years. The figures suggest that patent holders anticipate a significant demand increase in the future.

In contrast, least-developed countries have very limited access to foreign green technologies as they are mostly connected to the global economy through raw material markets.

Table 3: Low-carbon patent inflows, import of capital goods, foreign direct investments, economy size in selected emerging economies as a share of world total

Country	Patent inward flows ^a	Import of low-carbon equipment ^b	FD inward FDI links ^c	Economy size (2009 GDP)
China	15.5% (12.2%)	8.3% (15.3%)	7.1%	11.1%
Mexico	2.2% (1.6%)	1.7% (3.0%)	2.5%	2.2%
Russia	1.3% (0.9%)	1.4% (1.8%)	2.2%	3.3%
South Africa	1.2% (0.8%)	0.4% (0.6%)	0.9%	0.7%
India	n.a. (n.a.)	1.5% (1.5%)	1.6%	4.9%
Brazil	0.7% (0.5%)	0.7% (1.1%)	2.5%	2.9%

Source: Glachant et al., 2013 based on PATSTAT, COMTRADE and ORBIS data. Notes: Results for all technologies and equipment good appears in parentheses. ^a Average of patent flows covering 23 technology classes, except agriculture and forestry (2007-2009). ^b Average of low-carbon equipment from 18 products/sectors: hydro, wind, solar photovoltaic and thermal, nuclear, energy storage, electric and hybrid vehicles, rail locomotives, cement, insulation, lighting, economizers, super-heaters, soot removers, gas recoverers (2007-2009). ^c Count of capital links between a source company owning at least one low-carbon patent and a foreign company in 2011.

What about South-South technology transfer? Glachant et al. (2013) find contrasted results. The transfer of climate-related patents or FDI flows between developing countries hardly exists (less than 1% of cross-country patent flows, 1.9% of FDI links), but trade becomes significant (10% of the world total). Recall however that trade is a less knowledge-intensive channel of technology transfer.

Innovation through learning-by-doing

This form of innovation is obviously far more difficult to characterize and quantify as it comes through diffuse incremental improvements made by line workers or others not officially designated as engineers or lab technicians across the value chain. But there are strong reasons to think that learning-by-doing is very active in countries where manufacturing is set up.

3 Policy Issues

How to create an enabling environment for innovation and international technology diffusion, in particular in the developing world? That is, a set of government policies and conditions creating and maintaining an overall macroeconomic environment favorable to innovation and technology diffusion? The goal of this part is to identify and assess various components of such environments.

3.1 Creating Demand

Creating demand for green technologies via environmental policies inducing pollution abatement and environmental protection is a prerequisite for green innovation and technology diffusion. The reason is that cutting emissions or protecting the environment is generally not privately profitable yet under standard market conditions. In the absence of public policies providing incentives and imposing constraints on emissions and polluting practices, households and corporations are thus unlikely to adopt green technologies. This conveys what is probably the most important message of our policy discussion. Increasing innovation and diffusion of technologies can only occur in the presence of ambitious environmental policies with proper enforcement (e.g., carbon taxes, Cap & Trade system, emission standards, etc.). This has been documented by many studies both for innovation (Brunnermeier and Cohen, 2003; Newell et al., 1999; Popp, 2002; Crabb and Johnson, 2010) and international technology diffusion (Lanjouw and Mody, 1996; Popp *et al.*, 2007; Verdolini and Galeotti, 2011, Dechezleprêtre et al., 2013).

Environmental policies are designed and implemented at the national level, and they tend to be stricter in advanced economies as developing countries logically give priority to economic development and poverty alleviation. Can developing countries then participate in the greening of global value chains, acquire green techs and innovate without ambitious environmental policies at home?

The answer is yes for technology transfer as illustrated by the photovoltaic industry. In just a few years, China became a world leader in the manufacturing of both photovoltaic panels. Chinese PV companies acquire the necessary technologies to export cells and panels in countries such as Germany, Spain, or the US where feed-in tariffs and renewable portfolio standards trigger massive installations of PV production capacities. In fact, if barriers to trade and transportation costs are low and if the developing country's workforce is sufficiently qualified, there are no reasons why production and the necessary technologies remain located in the countries with environmental demand.

Of course, it could give birth to serious political difficulties: Political leaders in many countries frequently argue that ambitious environmental and climate domestic policies can help local firms achieve technological leadership, thereby improving the competitiveness of the national economy. But

if these policies also strengthen foreign competitors, this might weaken their ability to generate a competitive advantage. In turn, this creates a risk of trade war as illustrated today by the conflict on photovoltaic panels between China on the one hand, and the US and the European Union on the other hand.

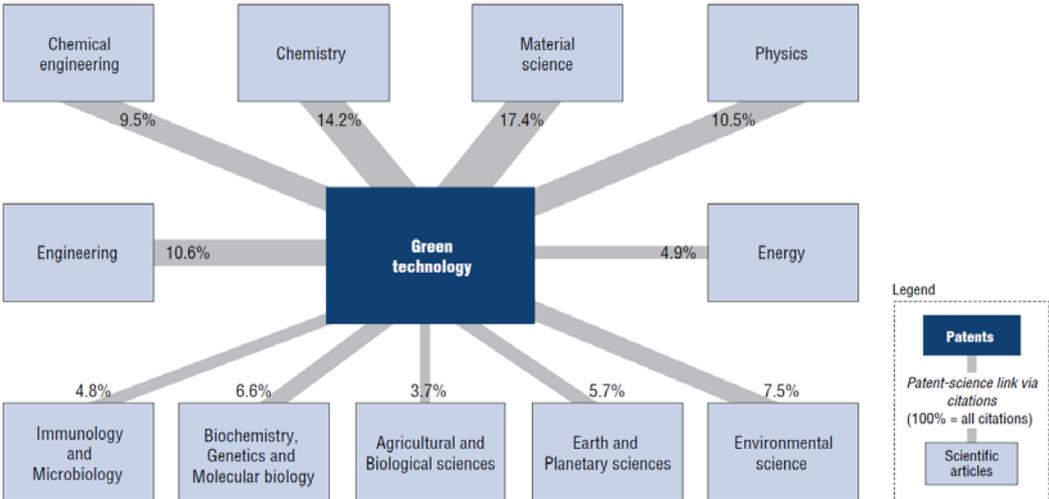
The answer is less obvious for innovation. Two recent studies on wind and solar technologies even show that the impact of foreign environmental policies on local innovation is much lower than that of domestic demand (Dechezleprêtre and Glachant, 2011; Peters et al., 2012). These results suggest that the international division of labor could lead to the specialization in innovative activities of certain (industrialized) countries with stricter environmental policies.

3.2 Technological Capacity Building

Technological capabilities – such as availability of skilled technical personnel, information on available technologies, social institutions that reduce transactions costs – determine a country’s ability to successfully innovate and absorb foreign technologies. Eaton and Kortum (1996) show for instance that countries with strong absorptive capacities such as Japan and European OECD countries derive almost all of their productivity growth from R&D carried out abroad. Absorptive capacities also facilitate local knowledge spillovers from international trade and FDI, and thus wider diffusion of this knowledge within the recipient country.

Helping developing countries to build absorptive technological capacities should thus be given priority through various means, including education, cooperative research, development and demonstration programs. As shown in Figure 1, green technologies draw on scientific knowledge from many sciences, among which energy and environmental sciences only account for about 12 percent. It suggests that encouraging education and training in narrow technology fields may be less important than generic programs addressing a broad range of disciplines.

Figure 1: The innovation-science link in green technologies (2000-2007)



Source: Measuring Innovation: A New Perspective, OECD (2010)

3.3 The Role of Trade and FDI Barriers

As argued before, international technology transfers take place through market channels such as trade or FDI. Accordingly, lowering barriers to trade and FDI is an effective policy leverage to foster the transfer of green technologies.

It is however worth discussing further the precise design of regulations in more detail. Non-tariff barriers such as local content requirements - which mandate to give preference to local contractors and locally manufactured materials and equipment – or regulations promoting joint ventures with a local partner instead of greenfield investments or mergers and acquisitions are widespread practices. They have been implemented in the wind industry in countries including Canada, China, Spain, Brazil, India, Australia and Portugal with varying levels of success. Another example is the Chinese law on CDM which says that the ownership of a foreign party in a CDM project shall not exceed 49%.

Such provisions have ambiguous effects on technology transfer and diffusion. On the one hand, they obviously lower the incentives for foreign companies to invest locally and reduce imports of equipment goods. On the other hand, they may help the diffusion of technologies *within* the economy. This is even the prime goal of regulation promoting joint-ventures which allows the transmission of knowledge and skills to the local partners. The net result of these two effects is likely to vary a lot across sectors and countries. But it can be positive in sectors and countries where the size of the market, the quality of infrastructure and the absorptive capacities are sufficient to attract foreign investors despite these constraints.

3.4 The Controversial Role of Intellectual Property Rights on Technology Transfer

Beside financial incentives such as R&D subsidies or tax credits, patent law is a key policy tool to create incentives to mitigate the incentive problem described in the first part of the paper. Patents confer upon their owner the exclusive right to make, use, and sell the protected invention for a maximum period of twenty years, during which the patent owner is able to extract profits from his invention. Keeping in mind that the prime goal of IPR is to promote innovation, whether a stronger IP regime fosters the transfer of climate-mitigation technology to developing countries is a controversial issue in international climate negotiations. Serious arguments with opposite conclusions are available:

- IPR is a property right, and the existence of property rights is a precondition for the emergence of markets that will diffuse technologies across market participants.
- In theory, a patent holder has two options. It can commercially exploit its invention. This limits the use of the invention, but not necessarily its impact if the products in which the technology is embodied are widely sold. Alternatively, the inventor can license its invention to other companies. IP can then restrict diffusion if royalty fees are high. In both cases, the outcome depends on the intensity of competition. If the technology does not have efficient and reliable substitutes, the inventor might be able to raise price barriers, hindering the diffusion of the technology itself or of the goods in which the technology is embedded. Conversely, a patent does not hinder diffusion if competition is fierce.
- In return for legal exclusivity, patenting requires the inventors to disclose publicly information on the technology. This publication generates positive knowledge spillovers as other inventors may draw inspiration to develop new technologies. This property of IPR is in sharp contrast with other tools used by innovators to appropriate technologies, such as trade secrets.

As a result, whether IPRs promote technology diffusion or not cannot receive a general answer solely based on theoretical arguments. Fortunately, several empirical studies have tested the different hypotheses. General studies dealing with all technologies suggest that strict IPR enforcement have an average positive effect on the volume of foreign technology transfers to developing countries. This effect is clear when the recipient country is technologically advanced and open to international trade (Sampath and Roffe, 2012). In this case, strong local absorptive capacities enable effective transfers, but also create a serious threat of imitation for foreign innovators (Maskus 2000; Smith 2001; Hoekman, Maskus, and Saggi 2005; Mancusi 2008; Parello 2008). Because it provides a safeguard against such imitation, strong IP protection then facilitates technology transfers in the recipient country. There is also empirical evidence that it encourages the use of knowledge-intensive channels such as FDI and licenses instead of the mere export of equipment goods (Smith 2001).

Several studies confirm these insights in the specific case of climate-friendly technologies. Dechezleprêtre et al. (2013), Barton (2007), and Maskus (2010) show that patenting has not been a barrier for the transfer of solar PV, wind power, and biofuel technologies in emerging economies. See also the analysis of the wind sector by Kirkegaard et al. (2009), that of the PV sector by Dechezleprêtre et al. (2011), and the study of the transfer of integrated gasification combined cycle—the most efficient coal power technology—to India (Ockwell et al., 2008).

These results are driven by the fact that climate-friendly technologies mostly exist in mature sectors wherein numerous substitutes can compete at the global scale. In this respect, the situation for low carbon technologies is not comparable today with the pharmaceutical industry in which certain drugs have no substitutes or with information technologies in which the existence of technical complementarity and compatibility issues induce “blocking” patents. But, there is no reason why green technologies would be immune to similar difficulties for eternity. In particular, the discovery of a “breakthrough” technology in certain sectors (e.g., CCS, smart grids, and biofuels) can change the landscape.

The case of less advanced countries that lack technological capabilities is different. In these countries, strengthening IP rights is not the key issue (Haščič et al., 2012). Stronger IP protection may even induce less transfers— as the threat of imitation is not a serious deterrent for foreign firms – but could generate stronger monopoly rents for foreign firms (Maskus, 2000; Smith, 2001).

3.5 The Clean Development Mechanism

The Clean Development Mechanism of the Kyoto Protocol (CDM) allows industrialized countries that have accepted emissions reduction targets under the Kyoto Protocol (Annex 1 countries) to develop or finance projects that reduce greenhouse gas emissions in other countries in exchange for emission reduction credits. While its primary goal is to save abatement costs, the CDM also provides technical and financial support for the diffusion of climate technology in non-Annex 1 countries⁸. If the technology used in the project is not available in the host country, the project leads *de facto* to a cross-border technology transfer.

Several empirical studies have been conducted in order to assess whether the CDM has encouraged North-South technology transfer (de Coninck et al., 2007; Haites et al., 2006; Seres, 2007; Dechezleprêtre et al., 2008; Schneider et al., 2008). They conclude that roughly 40% of CDM projects induce a technology transfer. These transfer mostly concern technical equipment and/or know-how,

⁸ Note that the CDM did not originally have an explicit technology transfer requirement in the Kyoto Protocol. This was included later in the 2001 Marrakech Agreement.

rather than patented inventions⁹. They are more frequent in large projects, and in projects directly involving Annex 1 companies either through local subsidiaries or as credit buyers in the project.

Despite these achievements, it is widely admitted that the CDM falls short of achieving the full potential of developing countries in terms of both GHG abatements and technology diffusion. A first general explanation lies in the high transaction costs that result from the tight evaluation methodologies and monitoring procedures required for each project (see e.g., Hampton et al., 2008). The CDM framework is also inappropriate when the scale of the project cannot account for all the economic mechanisms at stake – for instance when there are synergies or economies of scale between different projects (Glachant and Ménière, 2011). CDM methodologies similarly prove ill-suited to complex projects involving capacity building and/or public policy actions (e.g., a modal shift in the transport sector, or smart-grid transition).

Against this background, several evolutions of the CDM have been envisaged so far, which all consist in relaxing the mechanism by widening the scope of projects. A first modest step in this direction has been made with the implementation of *programmatic* CDM, which consists in pooling several CDM projects within one single "program" so as to reduce the transaction costs of their formal validation.

More importantly, the Durban Platform adopted in the 2011 COP commits parties to formulate a so-called New Market Mechanism (NMM) under the 2015 agreement. The nature of this mechanism remains vague and rule-setting has been deferred to the 2013 COP in Warsaw. In contrast with the CDM, the NMM could be sectoral in nature. It would go beyond the pure offsetting of emissions and produce a net atmospheric benefit. It could also include sectoral crediting or trading, forming a stepping stone towards a system of globally linked economy-wide cap-and-trade systems.

Like the CDM, the prime goal of the NMM would not be technology transfer. But there are good reasons to think that it can perform better along dimension in comparison with the CDM. The sectoral scope allows economies of scale and better coordination in the removal of common technological and financial barriers. It enhances possibility of using public policy levers at the sectoral level, which can focus on infrastructure investment and development of technical capacity needed to achieve projects (capacity building). It could also facilitate the internalization of learning spillovers.

3.6 Governmental Environmental Agreements

The CDM and the NMM are instruments of the United Nations Framework Convention on Climate Change (UNFCCC). It is worth opening a more general discussion about the potential contribution of international environmental agreements to innovation and technology diffusion. To begin with, such agreements necessarily increase the demand for green technologies in participating countries. They thus boost domestic innovation and the import of foreign technologies as established for example by Dekker et al. (2012) in the case of the Convention on Long-Range Transboundary Air Pollution.

The effectiveness of multilateral agreements however depends on the precise instruments used. In this respect, many commentators suggest to rely on technology-oriented instruments, in particular because they are seen as more acceptable by the negotiating parties than emissions-based approaches (for instance, see Ockwell, 2010). In this respect, a Technology Mechanism was established as an

⁹ Technology transfers mainly concern two areas, namely i) wind power and ii) end-of-pipe destruction of non-CO₂ GHG with high global warming potentials (such as HFCs, CH₄ and N₂O) in the chemicals, agricultural and waste management sectors. Other projects, such as electricity production from biomass or energy-efficiency measures in the industry sector, mainly rely on local technologies (Dechezleprêtre et al., 2008).

institutional entity in 2010 under the UNFCCC. It is meant to facilitate the implementation of enhanced action on technology development and transfer in order to support action on mitigation and adaptation to climate change. It consists of two components:

- A policy-making body called the Technology Executive Committee (TEC) comprising 20 high level independent expert members, elected by the COP. The mandate of the TEC is to support the design and coordination of inclusive action programs for technology transfer and diffusion, based on a thorough review of priority needs and barriers in recipient countries.
- A Climate Technology Center and Network (CTC&N). The CTC&N currently exists only on paper until it is hosted by another pre-existing organization. It will get to implement actual transfer of technologies and perform its functions as mandated by the Conference of Parties of the UNFCCC. The Climate Technology Centre shall facilitate a network of national, regional, sectoral and international technology networks, organizations and initiatives with a view to engaging the participants of the Network in effectively carrying out technology development and diffusion.

It is obviously not possible to conclude about the effectiveness of the Technology Mechanism for its precise activities have not been defined yet. But evaluation of previous experiences of technology-oriented arrangements yields positive conclusions. For instance, Hascic et al. (2012) have shown that the multilateral energy technology initiatives have had a very strong positive impact on transnational cooperative R&D activities (measured by the count of patented co-inventions). Another illustration is the so-called Multilateral Fund for the Implementation of the Montreal Protocol which helps developing countries to meet the agreed incremental cost of fulfilling the Protocol's control measures.

3.7 Business-led Agreements

Business-led initiatives are broad international agreements between companies belonging to the same sector, in order to better coordinate their environmental actions through information sharing, technology sharing, or joint technology development.

As an illustration, the Cement Sustainability Initiative (CSI) aims to develop a sustainable development strategy for the cement industry, and therefore incorporates climate change mitigation in its objectives. In February 2011, this initiative included 23 major cement groups, represented in more than 100 countries, and accounting for more than 40% of world production. Another example is Worldsteel which aims to promote a sustainable development of the steel industry or the International Aluminum Institute (IAI) including 27 industrial companies that represent about 80% of world production.

Yet so far industry-led initiatives do not seem to have performed major achievements in terms of carbon abatement and technology development and diffusion. Most of the actions initiated by the CSI, IAI and WorldSteel are limited to benchmarking and sharing best practices. Only Worldsteel has launched a long-term R&D cooperation, while the ambitions of CSI in the matter have not materialized yet. These modest achievements pertain to the lack of incentives for firms to actively cooperate in sharing strategic information and technology with their rivals. Since industry-led initiatives are primarily meant to anticipate the implementation of binding sector regulations in a large enough number of countries, they may yet come to play a more important role were such regulations to be adopted (or the threat thereof to be serious). In that case, they could prove an interesting instrument to shape and harmonize these regulations at the international scale - including by

facilitating the participation of developing countries in such policy schemes – and to organize joint compliance through the development and diffusion of clean technologies.

4 Conclusion

Based on a well-developed academic literature on innovation and technology diffusion, we have tried to describe how developing countries, in particular, emerging market economies, are innovating and adopting green technology today and what policy approaches could foster their participation in the globalization of knowledge, technology, and skills.

In practice, knowledge, skills and technologies mostly flow across countries through international trade of equipment, foreign direct investments, joint-ventures and the associated circulation of skilled workers. Hence economic globalization implies technology diffusion, almost by definition. In contrast, economic globalization does not so directly induce the globalization of innovation. One can even think that the international division of labor could lead to the specialization of certain (industrialized) countries in innovative activities. Evidence from previous literature tends to confirm this hypothesis.

The patterns of innovation and technology diffusion and policy challenges are different for emerging economies and least-developed countries. The former group of countries is integrated in the global economy with varying degrees. As a consequence, technologies already flow in through the imports of capital goods and local investments by multinational enterprises owning technologies. Technology providers are mostly located in industrialized countries whereas South-South technology transfer is very limited. For the most part, technology diffusion towards the developing world is driven by a demand for green technologies induced by environmental policies in industrialized countries (including through the Clean Development Mechanism). Pushing further technology transfer towards these economies requires strengthening intellectual property rights, lowering barriers to trade and investments and improving technological absorptive capacities.

In contrast, statistics show that the role of emerging economies in the development of new technologies is limited. Standard tools of innovation policy - public R&D, public support to private R&D, better access to finance - should develop. But studies also suggest that governments should introduce more stringent environmental policies with proper enforcement at home (e.g., stricter emissions standards, cap and trade schemes, pollution taxes) to go beyond the adoption of foreign technologies.

The situation of least-developed countries is very different: they do not import green technologies and low barriers to trade and FDI or strict intellectual property rights are unlikely to trigger technology transfer. In these countries, the focus should be on building technological capacities.

Research Gaps and Issues to Be Discussed

Although the literature has developed quickly (see the length of the list of references below), much remains to be done and many issues need to be discussed:

1. Many technology fields and sectors have received less attention than climate-related and energy technologies. In particular, little is known about innovation and green technology diffusion in agriculture and forestry.

2. As mentioned previously, international cooperation may constitute an effective means to promote the globalization of knowledge and skills. But the precise design and the effectiveness of various technology-oriented instruments to be implemented under international agreements deserves more discussion and analysis (financing mechanisms, cooperative research programs, etc.).
3. Developing countries need methodologies and roadmaps to identify priority technologies and to adapt the policy instruments to local context. Some works have been done (e.g., technology need assessments under the UNFCCC), but much remains to be done.
4. The distinction between emerging economies – which are increasingly integrated at various stages of global value chains– and least-developed countries – with economies mostly based on agriculture, forestry and the production of raw materials – is absolutely central. How should we differentiate policy approaches related to Intellectual Property Rights, trade regulation, capacity building, etc.?
5. Once a foreign technology is available in the country, how it disseminates in the recipient economy is of utmost importance. Combining the promotion of technology imports and internal diffusion is a tricky issue for the two objectives may contradict each other. In particular, private actors transferring the technology usually seek to restrict its subsequent dissemination in the host economy, in particular towards potential competitors.
6. How can poverty alleviation and the international diffusion of green technologies complement each other?
7. Some industrialized countries and corporations clearly fear that technology transfer would damage their competitiveness. How to maximize win-win solutions?

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