What role for climate negotiations on technology transfer?

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Abstract

Little progress has been made in the climate negotiations on technology since 1992. Yet, we provide evidence that the diffusion of climate change mitigation technologies to developing (non-Annex I) countries has increased dramatically over the last twenty years. This has mostly concerned emerging economies which are now reasonably well connected to international technology flows. This is good news as these are the countries where the bulk of emissions increases is expected in the near future. In contrast, least developed countries appear to have remained excluded from international technology flows, mostly because of their little participation in the recent economic globalization. This evidence leads to the perhaps controversial view that climate negotiations can safely continue to neglect technology issues. However, they have a key role to spur the demand for low carbon technologies through the setting of ambitious emission reductions objectives and policies.

Keywords: climate innovation, climate-mitigation technologies, international technology transfer, innovation policy, intellectual property rights, trade, economic globalization.

JEL codes: F18, F64, O3, Q55

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1 Introduction

Technology has been an important topic of international climate change negotiations since the adoption of the United Framework Convention on Climate Change (UNFCCC) in 1992, in which the parties committed themselves to “promote and cooperate in the development, application and diffusion, including transfer, of technologies”. North-to-South technology transfer has been given a particularly high importance since technologies have so far been mostly developed in industrialized countries, but are urgently required to mitigate greenhouse gas (GHG) emissions in emerging economies where the bulk of future emission increases are expected.

Negotiations have been difficult between developing countries, which see technology transfer as a costly process that should at least partially be funded by developed nations, and industrialized countries which fear that aggressive technology transfer policies might deprive their innovative firms of vital intellectual assets. For these reasons, policy debates have so far revolved around the financing of technology transfer and the role of intellectual property rights (IPRs), which some countries view as a barrier to technology diffusion (Abdel-Latif, 2015). Important landmarks of the negotiation process were the Technology Transfer Framework adopted in 2001 as part of the Marrakesh Accords and the Poznan Strategic Programme on Technology Transfer in 2008. But the negotiation has taken the main step forward in Cancun in 2010 when the so-called Technology Mechanism was established.

The term “technology mechanism” can be misleading as, by analogy with the Clean Development Mechanism, it suggests some trading scheme whereby entities developing a technology-related project could receive carbon credits. The technology mechanism is very different. It is a coordination scheme made of two components: A body called the Technology Executive Committee (TEC) comprising 20 independent expert members whose role consists of identifying countries’ technological needs and providing governments with recommendations on policies that can promote technology transfer; and a Climate Technology Center and Network (CTCN) which facilitates a network of national, regional, sectoral and international technology networks, organizations and initiatives. The outcome might be seen as disappointing for the TEC is mostly a new forum to discuss future solutions that remain to be developed, and the CTCN has a limited capacity with an annual budget of only USD 14 million in 2015. A benefit of the creation of the Technology Mechanism is certainly that the discussion has been moved to a less politicized forum as TEC members are not government representatives, but independently appointed experts. But the benefit is arguably limited for a negotiation initiated more than twenty years ago.

In this paper, we show that, despite the absence of significant of progress on climate negotiations, North-South transfer of climate mitigation technologies has dramatically increased since 1992. This has mostly concerned emerging economies which are now reasonably well connected to international technology flows. This is good news as these are the countries where most of emission increases are expected to occur in the near future. In contrast, least developed countries appear to have remained excluded from international technology flows. This is not that problematic in the short run as their emissions are still limited, but we think these countries present the critical challenge for the future that the negotiation should be dealing with in the coming years, and we offer some thoughts on what could be on the agenda for the future negotiations.

The evidence presented in this paper is based on an up-to-date analysis of the climate-related technology transfer landscape, based on a combination of patent data, bilateral trade data and foreign investment data. To the authors' knowledge, this is the first time that such a comprehensive database on climate-related technology transfer has been assembled. Existing studies have essentially relied on two sources of data to describe climate-related technology flows: Clean Technology Mechanism (CDM) projects (Dechezleprêtre et al., 2008; de Coninck et al. 2007; Haites et al., 2006; Schmid, 2012; Schneider et al., 2008; UNFCCC, 2007, 2008 and 2010; Murphy et al., 2015) and patent data (e.g., Dechezleprêtre et al., 2011, 2013; Hascic and Johnstone, 2011).[1] Despite its success, the Clean Development Mechanism only presents a very partial view of global technology transfer of climate change related technologies towards developing countries. The coverage offered by patent data is potentially wider, but using foreign patenting as an indicator of technology transfer[2] is not without limitations: not all inventions are patented; the value of individual patents is heterogeneous; the propensity to patent differs between sectors and countries, and last but not least, filing a patent in a recipient country does not guarantee that the technology will actually be transferred.

To overcome the limitations of CDM and patent data, we combine data on the trade of low-carbon equipment goods, climate-related Foreign Direct Investments (FDI) and patents. The economic literature on technology diffusion views trade and FDI as two crucial channels through which technologies flow across borders. The import of capital goods, such as machines and equipment,

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[1] An exception is the study by Pueyo and Linares (2012) on renewable energy technologies who collected data on trade of equipment and installed capacity of renewable capacity weighted by claims of technology transfer observed in CDM projects (see the paper for details on the methodology). The scope is however more limited than our study which covers a wide range of climate – mitigation technologies.

[2] The fact that an inventor located in a country applies for patent protection in a foreign country is an indication that the inventor expects to transfer the technology as patenting gives the exclusive right to commercially exploit the technology in that country.

entails technology transfer for such goods embody technologies which can then bring productivity benefits in the recipient countries while 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).

The structure of the paper is as follows: We start by briefly summarizing the history of the climate negotiations on technology. We then present the indicators we have constructed to measure the cross-border transfer of low-carbon technologies since 1992. The next section describes current patterns and trends in technology transfer. We then interpret these results and draw implications for the international coordination on technology issues.

2 A brief history of the negotiations on technology

As explained in introduction, the negotiation on technology has a long history as technology development and diffusion is the fourth commitment of the parties in Article 4 of the UNFCCC signed in Rio in 1992.[3] The convention also includes specific commitments by developed countries to transfer technologies in the developing world (see paragraphs 3, 7, 8, and 9 of Article 4 and Article 11). This focus on technology transfer relative to innovation meets a pressing demand from developing countries. In the convention, technology transfer is also systematically related to the transfer of financial resources to the South, in particular in its Article 11 which proposes the creation of a financial mechanism. This reflects the dual role of technology in the treaty. First, North–South transfer is obviously required to gain access to technologies which have mostly been developed in industrialized countries[4]; but, in addition to finance, it is also viewed as a vector to compensate the developing world for the historical contribution of industrialized countries to climate change. Distributional issues are thus immediately at the core of the discussions on technology.

We will not describe in detail all the next negotiation steps, but provide an overview which illustrates how slow the process was. While the issue was being discussed in every COP after 1992, the first significant step was made with the Marrakesh Accords in 2001 which included the so-called technology transfer framework. The framework essentially defined five working themes - technology needs assessments, technological information, enabling environments, capacity-building, and mechanisms for technology transfer – and established the Expert Group on Technology Transfer

[3] A briefing note on the history of negotiations on technology has been published by the TEC (2011).

[4] As an illustration, Dechezleprêtre et al. (2011) even show that around 60% of the climate change mitigation inventions patented between 2000 and 2005 have been made in just three countries, namely Germany, Japan and the United States.

(EGTT) to discuss how to operationalize the framework. The next significant steps were probably the COP13, held in 2007 in Bali, where technology became one of the four pillars of an expected post-2012 climate change regime, and the Poznan strategic programme on technology transfer adopted in 2008 in COP 14 which modestly allocated USD 50 million to the funding of technology needs assessments and to pilot technology projects.

Then came the adoption of the Technology Mechanism in 2010 in COP 16. The TEC of which official role is to "Provide an overview of technological needs and an analysis of policy and technical issues related to climate technology development and transfer"[5] has held 11 meetings since 2011, spending much time to define working modalities and procedures. It has then focused its discussions on the so-called Technology Needs Assessments, which are reports submitted by developing countries in which they identify the key technologies they need to reduce their emissions and adapt to climate change. The TNAs also assess the barriers to the large-scale adoption of climate-related technologies. As of October 2015, these reports have been submitted by 78 countries and there is a large variation in their quality (Kim et al., 2013).

The Climate Technology Centre & Network is supposed to develop more concrete actions by providing technical assistance to meet specific requests made by individual countries. As of June 19, 2015, 27 requests have been made. As an example of request, Mongolia, which is revising its Renewable Energy Law, has asked for reviews by experts of existing foreign laws and advices on various issues such as competitive bidding for license to renewable energy producers or plans of energy conservation. To achieve this goal the CTCN relies on its network of regional and sectoral experts from academia, the private sector, and public and research institutions.

The situation will probably not change in the coming years. In particular, the Annex to the Lima call for climate action ("Elements for a draft negotiating text") on technology development and transfer adopted in COP 20 which is supposed to bring elements for a draft negotiating text in COP 21 leaves all options open, including no commitment on technology, except the strengthening of existing tools, in particular, in particular, the Technology Mechanism.

Based on this brief review of technology negotiations and outcomes under the UNFCCC and although robust evidence is lacking, a reasonable conclusion is that these activities have had probably little impacts on technology transfer on the field since 1992. This does not mean that the UNFCCC as a whole did not induce technology diffusion. In particular, the Clean Development Mechanism of the Kyoto Protocol (CDM) has had significant impacts in many emerging economies (see Murphy et al.,

[5] See http://unfccc.int/ttclear/pages/tec_home.html. Last accessed 20 June 2015.

2015, for the most up-to-date review of technology transfer within CDM projects). We come back to the impact of the other components of the climate negotiations in section 4.2.

3 Measuring technology transfer

We will now explore what has occurred in the field since 1992. How does technology-related knowledge flow from one country to another? 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. Its measurement is therefore inherently difficult. The economic literature[6] 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 the 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 to German, US and Japanese suppliers (de la Tour et al., 2011). They are now able to produce production equipment on their own.

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 a direct access to the technology. FDI might also generate local spillovers through labour turnover if local employees of the subsidiary move to domestic firms (Fosfuri, Motta and Ronde, 2001). Local firms may also increase their productivity by

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

observing nearby foreign firms or becoming their suppliers or customers (see, for example, Ivarsson and Alvstam 2005, Girma *et al.* 2009). Many studies have found empirical evidence that as a consequence of these spillovers FDI raise the level and growth rate of productivity of domestic manufacturing industries (Xu 2000, Liu 2002 and 2006, Keller and Yeaple 2003). Overall thus, 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. The very purpose of licensing is finally to carry out a full knowledge transfer to the licensor so as to enable it to exploit the technology directly. Accordingly, knowledge leaves both the source country and the source company, and now lies in the hands of a local third party. In practice, international licensing mostly concerns three sectors: chemicals, drugs, and electronics and electrical equipment.

This description of these major channels of technology diffusion 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. In addition, although all channels involve some degree of knowledge diffusion, trade in goods is significantly less knowledge-intensive than FDI, and FDI than licensing.

Table 1 : Knowledge location and mechanisms of internal diffusion in the different transfer channels

Transfer channels	Knowledge location	Diffusion mechanism in the recipient country	Size of knowledge transfer
International trade in intermediate goods	Source country	Reverse engineering	Limited
Foreign direct investment (incl. joint ventures)	Recipient country	Reverse engineering + labour circulation + local partner opportunism	Medium
Licensing	Recipient country	Reverse engineering + labour circulation + customer opportunism	Large

The above channels suggest three indicators to assess cross-country technology flow of climate change mitigation technologies: international trade of low-carbon capital goods, foreign direct investments made by companies active in the low carbon economy, and licensing data.

International trade data has been used in a large number of papers to proxy for international technology diffusion since the seminal works by Coe and Helpman (1995), Coe, Helpman, and Hoffmaister (1997 and 2008), and Eaton and Kortum (2001, 2002). Trade data is readily available from public sources, in particular the United Nations COMTRADE database, which reports bilateral trade between countries at a highly disaggregated product level. Trade data in the COMTRADE database covers between 70% to 90% of world trade depending on the year, and is thus reasonably complete. The very detailed classification system used in the COMTRADE database (a 6-digit classification of commodities) makes it possible to specifically identify trade in equipment goods that incorporate technologies to reduce greenhouse gas emissions (for example wind turbines). Such data have been used by Glachant et al. (2013) who identify trade flows in 14 different climate change-related technologies and use this data as a proxy for technology transfer.

Similarly, FDI data have been used intensively to measure international technology transfers (see for example Lichtenberg and van Pottelsberghe de la Potterie, 2001). However, FDI data are only available at a level that is too aggregated to be able to identify investments specifically related to climate change mitigation. For this reason FDI data have very seldom been used to study low-carbon technology transfer. An exception is Glachant et al. (2013) who use data from Bureau Van Dijk's ORBIS database to measure technology transfer in 25 low-carbon technologies. The ORBIS database includes firm-level data on investment stocks in foreign countries (due to mergers and acquisitions, creation of a subsidiary, etc.). In order to identify foreign direct investment by firms involved in sectors related to climate change, the authors match the ORBIS database with the PATSTAT database (a global patent database, see below) and identify companies which own at least one patent in a climate-related technology. This makes it possible to provide an indicator of FDI at the technology level, since economic sector classifications are too aggregated to allow for meaningful analyses at the technology-level. For example, one can only identify companies in the "Production of Electricity" sector, but not in the renewable energy production sector.

Unfortunately, data on international flows of royalty payments (licenses) are known to be lacking, for the simple reason that licenses are subject of private contracts that are rarely made public. However, the evidence shows that technology transfers via licensing are of a much smaller magnitude than trade and foreign direct investment. Flows (sum of revenue and expenditure) of "technology balance of payments" in 2011 represented about 0.3% of GDP at the world scale, against 2.4% and 29.3%

respectively for Foreign Direct Investment and Exports of Goods and Services[7]. Smith (2001) finds that licenses to unaffiliated firms represented less than 0.1% of the total value of licenses, FDI, and exports of manufactured products from the United States to the rest of the world in 1989 (Smith, 2001). Moreover, Anand and Khanna (2000) find that about 68% of licensing contracts take place in only two sectors—chemicals and drugs (46%) and electronics and electrical equipment (22%)—of which neither strongly overlaps with climate-mitigation technologies. A recent study on the Chinese solar photovoltaic industry also confirms that patent licensing does not play any role in this sector; the key vectors are FDI and the trade of manufacturing equipment (de la Tour et al., 2011).

A drawback of the trade- and FDI-based indicators is that they do not directly measure cross-country information flow, but the flow of goods or capital with which they are presumably associated. The actual contribution to technology diffusion of trade in goods and foreign investment is likely to vary a lot across industries, markets and technologies. This is why we complement our assessment with patent data. As outline above, this constitutes a standard approach. Patent protection is relied upon for technology transfers along all three channels—trade, FDI and licensing—for each of them raises a risk of leakage and imitation in recipient countries (Maskus, 2000; Smith, 2001; Dechezleprêtre et al., 2013). Patenting can then be a measure of technology transfer because it gives the exclusive right to exploit commercially the technology in the country where the patent is filed. As patenting is costly, inventors request protection when they have plans to use the technology locally. For this reason, a number of studies have used patent data to measure international technology transfer of climate change mitigation technologies (Dechezleprêtre et al., 2011, 2013; Hascic and Johnstone, 2011).

The main advantage of using patents to measure technology diffusion is that they are available at a highly technologically disaggregated level. One can precisely identify innovations in various climate-related technologies whereas R&D investments, trade or foreign direct investment cannot always be disaggregated with the same level of granularity. Furthermore, patenting is more directly related to information and knowledge than trade and FDI statistics.

Using patents as an indicator of technology transfer is nevertheless not without limitations. To start with, not all inventions are patented, although a large fraction of the most economically significant innovations appears to have been patented (Dernis and Guellec 2001). The value of individual patents is also heterogeneous, implying that the simple count of patents is an imperfect measure of

[7] World Bank Indicators, http://data.worldbank.org/. However this indicator should be considered as an upper bound of the magnitude of technology licensing. Indeed, it also includes items that are not related to technology, such as royalties on trademarks or copyrights. Moreover, part of the patent royalties reflects intra-group transfers between entities of the same corporations in different countries: they are likely to proceed from tax optimization strategies rather than actual technology transfers.

the importance of technology transfer. This is less of an issue in the present study to the extent that we focus on “exported” inventions, which are typically more valuable than patents filed in a single country (Harhoff et al., 2003; van Zeebroeck, 2011). Another concern is that the propensity to patent differs between sectors, depending on the nature of the technology (Cohen et al., 2000). This explains why, when comparing technologies in the following, we do not rely on absolute figures (e.g., the count of patents in a given country), but on relative indicators (e.g., the share of patents from that country in the total number of patents filed at the world level in the same technology). Another limitation is that, although a patent grants the exclusive right to use a technology in a given country, we do not have any information on whether the technology has actually been used. Yet, the high expense of patenting deters the filing for protection in countries where the technology is unlikely to be deployed. Patenting is costly – in terms of both the costs of preparation of the application, and the administrative costs and fees associated with the approval procedure (Van Pottelsberghe and François, 2009). For example, in 2005, filing a patent at the European Patent Office (EPO) cost around €30,000 (Roland Berger, 2005). Inventors are therefore unlikely to apply for patent protection in a particular economy unless they are relatively certain of the potential market value for the technology. Indeed, empirical evidence suggests that inventors do not patent widely and indiscriminately, with the average invention only patented in two countries[8] (see Dechezleprêtre et al., 2011).

4. The level of international diffusion of climate-related technologies

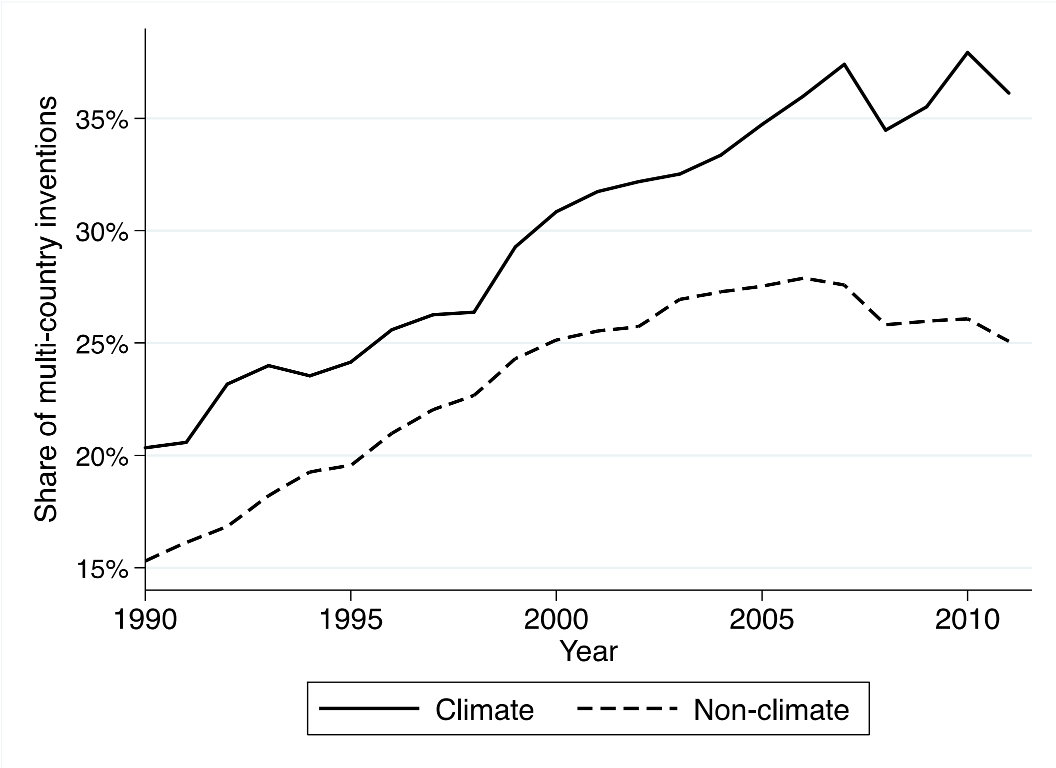
We will now describe the international diffusion of climate mitigation technologies. The first key message is that these technologies already cross national borders despite the absence of explicit international policies promoting technology transfer.

Figure 1 shows the evolution of the share of internationally-patented inventions since 1990 for climate-related technologies and other technologies. "International" inventions are inventions which have been patented in at least two countries and can be used as an indicator of the level of international diffusion. More than 35% of climate inventions were patented in more than one country in 2011. This proportion is much higher than the average for non-climate technologies (around 25%) and the gap between climate and non-climate technologies has been substantially increasing since 2000. Trade statistics show the same pattern with an annual increase in international trade of low-carbon equipment goods of 18% per year on average since 1990, compared to 13% for

(8) 75% of patented inventions are protected in only one country.

non-climate capital goods. The same trend is specifically observed for technology transfer towards the South increased significantly since 1990 and, as in the patent case, diffusion is around 50% higher for climate-related technologies than for other technologies on average.

Figure 1: Share of internationally-patented inventions, 1990 – 2011



Source: Authors' calculations based on PATSTAT data (see the details in Appendix 1.3. Note: Climate mitigation technologies covered are listed in Appendix 1.5.

This relative intensity of international diffusion of climate-related technologies is fortunate as most inventions are generated in a limited set of industrialized countries. The USA, Germany and Japan together account for almost 60% of the world's inventions. Moreover, innovation in climate-related technologies is more concentrated than innovation in non-climate technologies. Our data indicate that the relatively more intense diffusion may compensate for the more concentrated activity of innovation.

As a result of this evolution, technology transfer towards fast growing economies is now significant (see Table 2). In particular, with 29% of global imports of low carbon equipment goods, emerging countries play an active role in the international trade of these products. They are also significant exporters: 24% of the international trade of such goods originates from emerging economies. This indicates the success of countries like China in the production of equipment for producing renewable energy (e.g., photovoltaic panels, wind turbines). Statistics also suggest significant transfer through foreign direct investment (32% of the world's FDI links). The exchange of patents between the North and emerging economies is lower (16% of the world's flows). A possible explanation is that technology owners lack confidence in the enforcement of intellectual property rights in emerging economies.

The transfer of climate-related patents or FDI flows between emerging economies hardly exists (less than 1% of cross-country patent flows, 1.9% of FDI links), but trade between emerging economics is becoming significant (10% of the world's total). It is important to keep in mind, however, that trade embodies less knowledge than other channels of technology transfer.

The situation of least-developed countries is totally different. They have nearly no access to foreign green technologies as they are mostly connected to the global economy through raw material markets.

Table 2: Origin - destination matrix: distribution of exported patented inventions, international trade of low-carbon capital goods, and FDI links

Patent flows	Destination		
Origin	OECD	Emerging economies	Least developed countries
OECD	75%	16%	2%
Emerging economies	5%	<1%	<1%
Least developed countries	2%	<1%	<1%

Capital goods	Destination		
Origin	OECD	Emerging economies	Least developed countries
OECD	55%	19%	<1%
Emerging economies	14%	10%	<1%
Least developed countries	<0.1%	<0.1%	<0.1%

FDI links	Destination		
Origin	OECD	Emerging economies	Least developed countries

OECD	66%	30%	1%
Emerging economies	2%	2%	<0.1%
Least developed countries	0%	0%	0%

Source: Authors' calculations based on PATSTAT data, COMTRADE and ORBIS data (details are provided in Appendix 1). We use a 3-year average to mitigate the effect of annual fluctuations for trade and patents. Country groupings are described in Appendix 2.

In Table 3, we consider a particular set of large emerging economies. Along with the three channels of technology diffusion, as a comparison we report the size of each country measured as their share in the world's GDP. The table suggests that the intensity of technology transfers in China, Mexico and South Africa is in line with the economic size of the country. To a lesser extent, Brazil is also well connected to international flows of knowledge through FDI. In contrast, other emerging economies appear less integrated in the global flows of technology. This is particularly true for Russia and India: they account for 3.3% and 4.9% of the world's GDP whereas, depending on the indicator used, the size of inward transfers represents between 1.3 and 2.2% of world's flows for the former and only about 1.5% for the latter.

Statistics on technology transfer through the Clean Development Mechanism find results in line with these patterns: China hosts about 45% of the world's CDM projects (CDM Pipeline, 2013) and 59% of the Chinese projects involve a technology transfer compared to 12% for projects located in India, or 40% in Brazil (Dechezleprêtre et al., 2009).

As a whole, 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 to emerging economies is higher than that of non-climate ones, but international trade of low-carbon goods is lagging behind trade in non-climate capital goods (see statistics in parentheses in Table 3). 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 expected demand in the next 20 years. The figures suggest that patent holders anticipate a significant increase in demand in the near future. This is in line with the fact that the rate of diffusion is higher for technologies at earlier stages of development such as CCS, second generation of biofuels, and cleaner coal than the rate for mature technologies such as hydropower or energy efficiency in buildings (see Glachant et al., 2013, for a detailed technology-specific analysis).

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

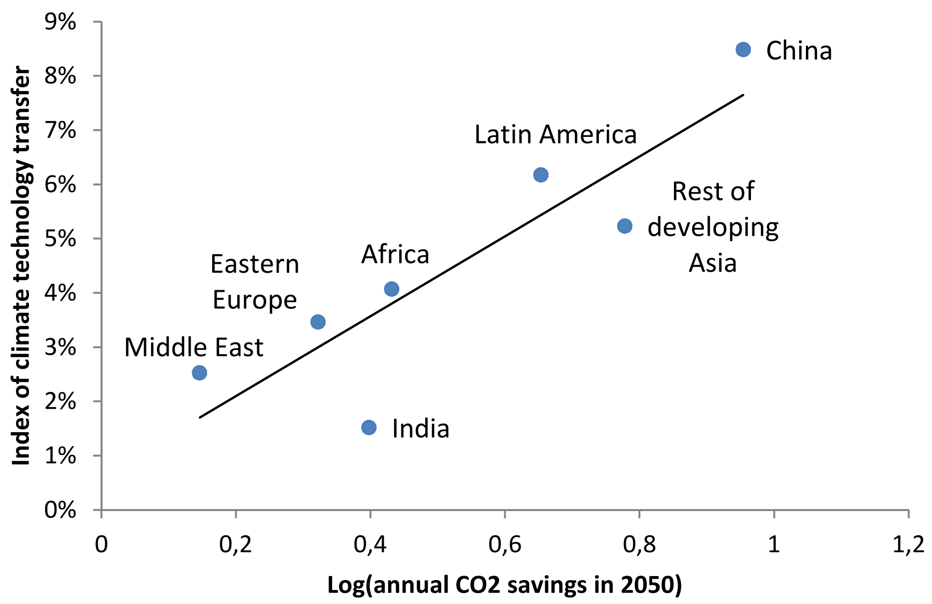
Country	Patent inward flows[a]	Import of low-carbon equipment[b]	FD inward FDI links[c]	Economy size (GDP)
Brazil	0.7% (0.5%)	0.7% (1.1%)	2.5%	2.9%
China	15.5% (12.2%)	8.3% (15.3%)	7.1%	11.1%
India	n.a.	1.5% (1.5%)	1.6%	4.9%
Mexico	2.2% (1.6%)	1.7% (3.0%)	2.5%	2.2%
Russia	1.3% (0.9%)	1.4% (1.8%)	2.2%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

Source: PATSTAT, COMTRADE and ORBIS data. Notes: Results for all technologies and equipment goods appear in parentheses. [a] Average of patent flows to the country as a share of world inward flows, covering 25 technology classes, except agriculture and forestry (2007-2009). [b] Average of the import of low-carbon equipment as a share of world imports, covering 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] Capital links between a source company owning at least one low-carbon patent and a foreign company in 2011 as a share of world total. More details are provided in Appendix.

Table 3 also gives an indication about the relative importance of the two main market channels of technology diffusion (FDI and trade of capital goods). Certain countries, like Mexico, Russia and Brazil, tend to rely more on FDI, which is good news as direct investment potentially entails larger knowledge transfer as explained in Section 3. More generally, there exists a lot of heterogeneity in the mechanism leading to technology transfer across sectors as illustrated by the transfer towards China in the wind and photovoltaic sectors. Although the outcome is similar - China's companies became world leaders in a few years - stories are completely different: PV companies became the largest exporters of PV cells and modules by purchasing western turnkey production lines and hiring top executives among the Chinese diaspora (de la Tour et al., 2011). Wind producers focused on the domestic market and accessed technologies through joint-venture and licensing agreements with western and Japanese producers (Kirkegaard et al., 2009). In both cases, competition played a key positive role by maintaining low prices (in the market of equipment goods in the PV sector, in licensing markets in the wind industry).

Table 3 thus suggests that India (and to a lower extent Russia) lags behind other emerging economies. But this is not necessarily a problem in the short run as the need for climate-mitigation technologies is lower in these countries. To investigate further this issue, we relate the intensity of technology transfer with the size of abatement potential (the amount of emissions' reductions that the implementation of the technology can achieve at a reasonable cost) for different countries and country groups. We use the McKinsey global greenhouse gas abatement curve describing abatement potential by 2030 at a cost less than USD 80/tCO_2. The graph shows a positive correlation between technology diffusion and the geographical distribution of abatement potential: the intensity of technology transfer (captured by an index which is the average of two of our indicators, FDI links and trade of low-carbon equipment goods) is higher in countries with larger abatement potential. Figure 2 identifies India and the rest of developing Asia as priority regions for technology transfer. In these regions, the abatement potential is large when compared with the current intensity of technology diffusion.

Figure 2: Abatement potential and index of technology transfer, by region (2007-2009)



Source: Authors' calculations based on McKinsey (2010), COMTRADE and ORBIS data. The straight line is estimated with the OLS method (R^2 = 0.7708). The index of technology transfer is the average of the share of imports to the region through trade, and FDI. The patent indicator is not used because data are not available for India.

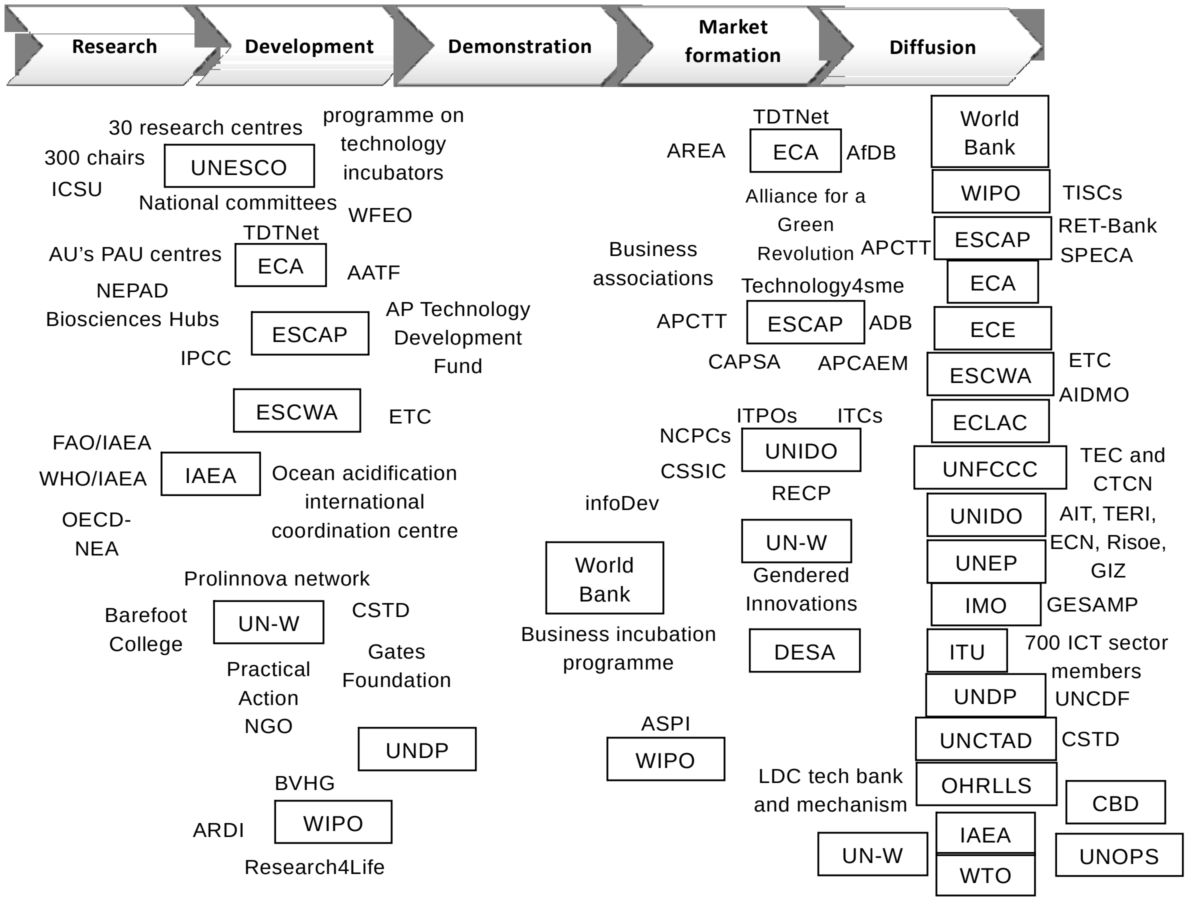
To conclude, there is clear empirical evidence that the international diffusion of climate change related technologies towards emerging economies is already happening at a high rate and has been increasing rapidly. This evolution has mainly been driven by the growing integration of emerging economies to the global economy, as technological knowledge mostly crosses borders though the international trade of capital goods and Foreign Direct Investments. The Clean Development Mechanism, which, contrary to expectations, has almost exclusively involved emerging economies, has helped creating a domestic demand for certain green technologies (e.g. wind energy in India and China). In other cases, climate-friendly technologies have been used to produce and export goods to meet a demand created by climate policies implemented in the North (e.g. solar photovoltaics). Similarly, the fact that least-developed countries remain outside can at least partly be explained by their little participation in the recent economic globalization.

5 Increasing climate-related technology diffusion: Is international coordination really necessary?

Even if the exploratory data analysis carried out in the previous section does not provide any causal estimate of the impact of international negotiations on technology transfer, the discrepancy between the arguably limited outcomes of the technology negotiations and the level of actual climate change technology transfer in the field casts serious doubts on the usefulness of past technology-related discussions under the UNFCCC. This is reinforced by the fact that hundreds of organisations outside the UNFCCC process are already involved in technology transfer activities. Figure 3 shows that, even when considering only United Nations and related (partner) organisations, international cooperation on technology transfer is already at the top of the agenda for a multitude of international bodies. It is also worth restating that firms are by far the prime owners of technologies globally. For example, between 2000 and 2012, among all climate-change related patents filed at the European Patent Office, the US patent office and the Japan Patent Office, only 5% were filed by public institutions (universities, government-funded research institutes and hospitals). The role of the private sector is thus absolutely critical (see also Kolk 2015).

This context calls for evaluating the added value of the UNFCCC as far as technology transfer is concerned. More generally, what should be the priority for the international coordination on technology diffusion in the future? The reality of technology diffusion being extremely contrasted between emerging economies and least-developed countries, the answer to these questions is necessarily different for these two groups of countries.

Figure 3: Overview of United Nations organisations and partnerships involved in technology transfer supporting activities



Source: United Nations Resolution A/67/348

5.1 The case of emerging economies

Promoting market-driven technology transfers. In the case of emerging economies, there is no reason to think that they will not continue to effectively absorb foreign technologies. In this group, certain laggards – South Asia and India in particular – will benefit from a growing participation in economic globalization. In this regard, lowering barriers to trade and to foreign investments is an important policy leverage to foster the transfer of green technologies. There is ample empirical evidence that technology diffusion is facilitated by an open trade regime (Saggi, 2002). Regarding climate change mitigation technologies in particular, Duke *et al.* (2002) show that the reduction of tariffs on solar modules in Kenya increased imports of PV systems. Looking at 13 climate change mitigation technologies (CCMT), Dechezleprêtre et al. (2013) show that lower tariff rates increase the diffusion of CCMT. Regarding FDI, evidence suggests that foreign investment responds to an adequate business environment, including governance and economic institutions (Maskus, 2004). Dechezleprêtre et al. (2013) find that controls over FDI significantly hinder technology flows of CCMT.

In this respect, Table 4 compares scores of the major fast-growing economies covered in Table 3 with different indices that measure trade barriers. The first column presents a widely-used index of trade regulation and control on foreign investments developed by Economic Freedom of the World; the second column is a climate-specific measure of import tariffs that we have constructed using the TRAINS database; the last column gives an index of IP rights strictness developed by the Global IP Center. Table 4 clearly shows that there is scope for improvements in emerging economies. The tariffs on low carbon equipment are particularly high in Brazil and India. The enforcement of patent rights seems particularly weak in Brazil, India and South Africa.

Table 4: Low-carbon patent inflows, import of capital goods, foreign direct investment, economy size in selected emerging economies as a share of world total

Country	"Freedom to Trade Internationally" index, 2012[a]	Average tariffs on low carbon equipment, 2013[c]	IP index, 2014[b]
Brazil	7.1	14.0%	1.25
China	6.7	3.3%	4.10
India	6.2	6.9%	1.00
Mexico	7.0	1.5%	3.24
Russia	6.0	3.9%	3.10
South Africa	7.2	2.6%	1.00
World average	7.0	6.1%	-
OECD average	8.8	1.7%	5.50[d]

[a] An index with scale of 1 to 10, where 10 is best constructed by Economic Freedom of the World. For more details, see: http://www.freetheworld.com/2014/EFW2014-POST.pdf.

[b] An index with scale of 1 to 7 which the strength of an economy's environment for patents, constructed by the Global IP Center. For more details, see: http://www.theglobalipcenter.com/.

[c] Extracted from the TRAINS database (http://wits.worldbank.org/wits). The number is an average of the tariffs applied to the low carbon capital goods included in our data, weighted by the value of trade in the different products.

[d] Data is not available for some OECD countries. The average is calculated for these countries: USA, UK, Switzerland, Germany, France, Japan, Australia, South Korea, New Zealand, Canada, Chile, Mexico.

The case of patent law deserves a longer development as some participants to the UNFCCC negotiation process argue that strict intellectual property rights may hinder the transfer of green technologies towards developing countries. Keeping in mind that the prime goal of IPR is to promote innovation, whether a stronger IP regime fosters international technology diffusion is a question for which 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.
- A patent holder has two options. S/he can commercially exploit the 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 the 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.
- From a theoretical point of view, strengthening the patent regime has an ambiguous effect on technology diffusion through international trade (Maskus, 2000): on the one hand, the restricted ability of local firms to imitate the product will increase foreign firms' incentives to transfer their technology (a market expansion effect); on the other hand, stronger patents will increase the market power of the firm, who will be able to raise prices which could in turn reduce demand (a market power effect), thereby slowing down diffusion (Maskus and Penurbati, 1995).
- In return of 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 secret. Consequently, strong IP protection may increase the diffusion of knowledge and hence of the underlying technology.

As a result, whether IPRs promote technology diffusion or not cannot receive a general answer solely based on theoretical arguments, and this question is ultimately an empirical matter, which has been tackled in a number of papers. Studies dealing with all technologies in general suggest that strict IPR enforcement have on average a 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. Smith (2001) shows that both trade flows and incoming FDI respond positively to increases in patent rights among middle-income and large developing countries but not among poor countries. In addition, the sophistication of technologies transferred also rises with the strictness of local IPR protection (Smith, 2001; Park and Lippolt, 2008). The reason behind these results is that patent protection is useless in countries with poor imitation capacities. There is also empirical evidence that patent protection encourages the use of knowledge-intensive channels such as FDI and licenses instead of the mere export of equipment goods (Smith 2001). Ivus (2010) evaluates the impact of strengthening patent rights in developing countries on developed countries' exports over a very long time-period (1962–2000) and finds that a strengthening of patent rights in developing countries raises the value of developed countries' exports in patent-sensitive industries. Perhaps not surprisingly, this effect is the strongest for industries that rely heavily on patent protection, such as medicinal and pharmaceutical products and professional and scientific equipment.

It is important to note that patent protection is important only in some sectors, because some products are more prone to imitation and more easily codified in a patent document. These sectors include the pharmaceutical, biotechnology, medical instrument and chemical sectors. In other sectors, patents are not perceived as an important means to protect innovation (Cohen et al., 2000). This has implications for environmental technologies, which for the vast majority do not belong to the sectors most dependent on patent protection. For example, Barton (2007) discusses from a legal perspective whether strong intellectual property rights in emerging economies would hinder or promote the transfer of renewable energy technology. He finds that patents could be a barrier for the transfer of solar PV technologies, but not for wind power and biofuels, because production is less concentrated in these two sectors. Similarly, Ockwell *et al.* (2008) show that IPR is not the main barrier to the transfer of integrated gasification combined cycle (IGCC)—the most efficient coal power technology—to India. Moreover, both studies underline that stricter patent protection may encourage technology transfer only if combined with strong absorptive capabilities. To conclude, patent protection does not seem to have been a barrier to the diffusion of climate change mitigation technologies so far (see also the analysis of the wind sector by Kirkegaard et al., 2009, and that of the PV sector by De la Tour et al., 2011).

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 where certain drugs have no substitutes or with information technologies where the existence of technical complementarity and compatibility issues induce “blocking” patents. But there is no reason that 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) could dramatically change the landscape. That is why one should keep an eye on this issue. In the meantime, however, the existence of large number of competing technologies and firms in the carbon emissions abatement sector makes it very unlikely that developing countries will be able to exploit compulsory licensing (initially meant to produce pharmaceuticals) to gain access to climate change mitigation technologies (Adam, 2009).

The literature thus plead for reinforcing patent rights in emerging economies like India, Brazil or South Africa as they clearly have the technological capacities to imitate. What does this imply for the UNFCCC negotiation process? Instruments targeting trade and foreign investments are traditionally regulated under the General Agreement on Tariffs and Trade (GATT) administered by the World Trade Organization. The WTO also implements the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) that sets down minimum standards for intellectual property regulation adopted in 1994. These agreements both offer some flexibility to introduce specific rules or exemptions to accommodate environmental policy objectives such as border carbon adjustments. This has been made very explicit for trade measures in a joint report by the WTO and UNEP (UNEP – WTO, 2009) which clarifies the conditions under which trade restrictions can be justified for climate change objectives. Flexibility is potentially lower under the TRIPS Agreement as its Article 27.1 requires that patent rules should not discriminate across fields of technology. But a WTO dispute settlement panel ruled that this provision only prohibits unjustified distinctions in patent law among technological areas and does not prohibit differences in legislation and processes based on legitimate policy preferences[9] (Maskus, 2010). The possibility has been used for pharmaceuticals. Against this background, there is serious reason to transfer the discussion of trade and IP rules from the UNFCCC to the WTO as both the GATT and the TRIPS seem sufficiently flexible to introduce climate-specific provisions if agreed by the parties.

[9] Canada-Generic Pharmaceuticals Case, WTO Doc. WT/DS1141R, 7 April 2000.

Creating a demand for low carbon technologies in emerging economies. In an often-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 as the markets for such drugs are too small to be of interest to multinational pharmaceutical companies. Rather than patents, 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 green technologies, one would expect demand (or the lack thereof) for clean technologies to be a primary constraint on international technology diffusion. The strengthening of environmental regulation is an important pre-condition to the diffusion of eco-innovations as cutting emissions is generally not yet profitable under standard market conditions. In the absence of public policies providing incentives for and imposing constraints on emissions, households and corporations are unlikely to adopt climate-friendly technologies.

A large body of work has empirically demonstrated that environmental regulation encourages the transfer of environment-friendly technology. Lanjouw and Mody (1996) find evidence that strict vehicles emissions regulations in the US led to the transfer of up-to-date technology from Japan and Germany into the US. Popp *et al.* (2007) examine the case of chlorine-free technology in the pulp and paper industry and find an increase in the number of patents filed by US inventors in Finland and Sweden after passage of tighter regulations in these countries. Similarly, they observe an increase in Swedish patents in the US following new regulation in this country. Dechezleprêtre et al. (2013) find that the strictness of climate change policies encourages international flows of CCMTs. Importantly, Dechezleprêtre et al. (2013) find that the only difference between the drivers of technology diffusion in general and the drivers specific to climate change technologies is the impact of climate change policies, which obviously matter only for CCMTs. All other drivers, including absorptive capacities, tariffs, FDI restrictions and IPR strictness are not different for CCMTs than for other technologies, suggesting that it the demand for CCMTs through green policies is the only specific policy which is needed to accelerate the diffusion of CCMTs globally. Other policies may be generic (for example, trade policies). This conveys what is probably the most important message of this discussion. Increasing diffusion of technologies towards emerging economies can only occur in the presence of ambitious climate policies (e.g., carbon taxes, cap-and-trade system, emissions standards).

Since 1992, the demand for low carbon technologies has increased in emerging economies through two channels: the Clean Development Mechanism (CDM), which increased domestic demand, and climate policies in rich countries, in particular countries committed to carbon emissions reductions under the Kyoto Protocol, which increased foreign demand. As a reminder, the 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 developing 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 countries[10]. 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; Murphy et al., 2015). They conclude that roughly 40% of CDM projects induce a technology transfer. These transfer mostly concern technical equipment and/or know-how, rather than patented inventions. They also induce very large financial transfers, including revenue from the sales of carbon credits. In 2012, the UNFCCC estimated that between USD 9.5 – 13.5 billion of credit were exchanged between 2007 and 2011 (UNFCCC, 2012). India, where around one half of the wind farms are registered under the CDM, has seen the development of domestic turbine manufacturers which initially served the domestic demand, but now compete in international market -- Suzlon is the 6th world producer with a global market share of 5.5% in 2014[11]. The same evolution was observed in China where almost all wind farms are CDM projects and which has also seen a dramatic growth of producers of wind power equipment. Four Chinese turbine manufacturers belong to the Top 10 world turbine manufacturers in 2014, Goldwing being the third behind Vestas and Siemens.

Corporations located in emerging countries have also imported technologies with a view to serving foreign demand driven by climate policies implemented in western countries. This is the second mechanism which has operated until now. It is illustrated by the photovoltaic industry, where Chinese PV companies acquired the necessary technologies abroad before exporting back PV cells and solar panels to countries such as Germany, Spain, or the US where feed-in tariffs and renewable portfolio standards trigger massive installations of PV production capacities. Chinese PV producers have acquired the technologies and skills necessary to produce cells and modules through two main channels: the purchase of manufacturing equipment in a competitive international market and the recruitment of skilled executives from the Chinese diaspora who built pioneer PV firms (de la Tour et

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[10] 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.
[11] Statistica.com: http://www.statista.com/statistics/272813/market-share-of-the-leading-wind-turbine-manufacturers-worldwide/. Last accessed: 23 June, 2015.

al., 2011). This development has been driven by foreign demand: Until very recently, Chinese cell and panel production was almost entirely exported in industrialized countries.

This period with a demand driven by the CDM and by climate policies implemented in the developed world is over. The registration of new CDM projects has almost completely stopped since the end of the first Kyoto commitment period 2008-2012 and the price of carbon credits generated by existing CDM projects is around zero (0.39€/tCO2 on 23 June, 2015[12]). Increasing the strictness of climate policies in industrialized countries is politically acceptable in the mid-term only if emerging economies also commit to control their emissions. This is where the current negotiations can provide the decisive contribution. Country commitments on future emission levels that will be made in Intended Nationally Determined Contributions (INDCs) are thus now the key issue for the acceleration of technology transfer to the South.

Against this background, the potential contribution of the Technology Mechanism is likely to be extremely limited. It should essentially provide local private and public actors with information to facilitate coordination (e.g. through technology needs assessment). The TEC can bring its expertise on green technologies to identify on a case-by-case basis some barriers that could emerge for certain technologies and that would then require a differentiated treatment with respect to trade or IP laws.

5.2 Least-developed countries

The situation of least-developed countries is paradoxical. On the one hand, it is more critical as they do not import green technologies; on the other hand, there is less urgency to deal with the problem as their contribution to global emissions will remain limited in the near future. In these countries, the priority is then to build technological capacities and to promote their integration into the global economy. In fact, the problem to be solved is very general: the economic under-development of certain countries and regions, in particular in Africa. In this context, the discussion of specific adaptation of trade and IP rules for low carbon technologies seem at odds with the challenges these countries face today.

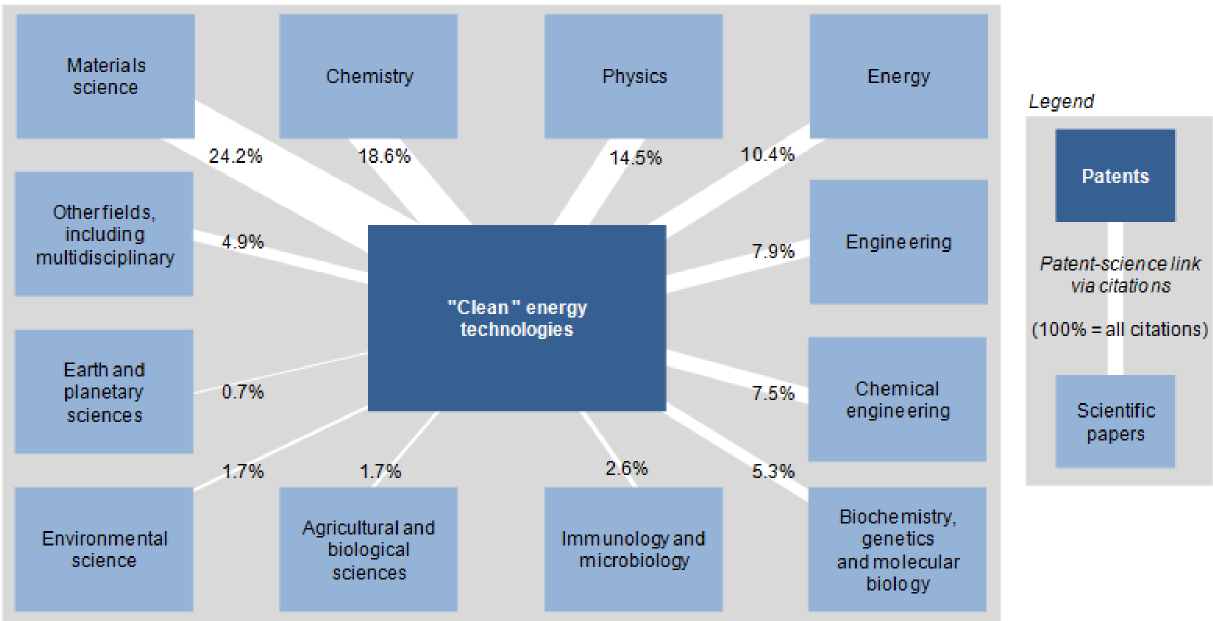
There is strong evidence that technological capabilities – such as availability of skilled technical personnel, information on available technologies, social institutions that reduce transactions costs – determine a country’s ability to successfully innovate and absorb foreign technologies. These skills are referred to as absorptive capacities (Keller, 1996). Low absorptive capacities encompass for example shortage of skilled technical personnel, lack of information on available technologies and

[12] https://www.eex.com

high transaction costs (Worrell *et al.*, 1997). Many studies indicate that technology diffusion increases with the level of domestic human capital (Eaton and Kortum, 1996). Moreover, local absorptive capacities increase local spillovers from trade and FDI. Borensztein *et al.* (1998) analyze the effect of FDI on economic growth in 69 developing countries and find that FDI has a higher productivity than domestic investment if the host country has a minimum threshold of human capital. The flow of advanced technology brought along by FDI can increase the growth rate of the host economy only by interacting with that country's absorptive capability. Smith (2001) finds that the sophistication of technologies transferred rises with the level of domestic absorptive capacities.

Building capacities should thus be given priority through various means, including education, cooperative research, development and demonstration programs. As shown by Figure 4, 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. Again, the UNFCCC – which focuses on climate by its very nature – is probably not the adequate framework to coordinate internationally on these issues.

Figure 4: The innovation-science link in green technologies (2000-2007)



Source: OECD (2010)

6 Conclusion

In this paper, we argue that the apparent lack of success of the climate negotiations on technology transfer has had little negative consequences on international technology diffusion until now. This evolution has mainly been driven by the growing integration of emerging economies to the global economy, as technological knowledge mostly crosses borders though the international trade of capital goods and Foreign Direct Investments. The Clean Development Mechanism, which has almost exclusively involved emerging economies contrary to the expectations, has contributed to create a domestic demand for green technologies in some developing countries (e.g. wind energy in India and China). In other cases, climate-friendly technologies have been used to produce and export goods to meet a demand created by climate policies implemented in the North (e.g. solar photovoltaics). Similarly, the fact that least-developed countries remain outside can be related to their little participation in the recent economic globalization.

What do these findings imply for future climate negotiations? They first suggest that climate negotiations could continue to neglect technology transfer issues. This does not mean that international coordination on technology transfer and technological capabilities is useless. But they might be better addressed outside the UNFCCC. These include efforts to reduce trade barriers and resolve intellectual property issues in emerging economies, which are best addressed through the World Trade Organisation, and generic capacity building in least-development countries which can be managed by the established international institutions in charge of economic development in the South (i.e. World Bank, UNIDO). In this international architecture, the UNFCCC will mostly contribute by spurring the demand for low carbon technologies through the setting of ambitious emissions reduction objectives and policies both in the North and the South. Ambitious climate change policies will also induce more research and development activities in low carbon technologies in countries with strong research capabilities (which include both developed and emerging countries), which will reduce the cost of deploying low-carbon technologies, thereby spurring their international diffusion. Within this framework, the Technology Mechanism could play a positive but modest role by providing stakeholders with information and technical assistance to facilitate technology transfer in the field.

These implications do not address the distributional dimension, which is essential in any negotiation. As explained in section 2, technology transfer has become a prominent issue in negotiations also because it is seen as a way to compensate the developing world for the responsibility of industrialized countries in creating the atmospheric stock of carbon dioxide. This is why we believe important to establish a strong link in the international discussions between the Technology

Mechanism and finance. In particular, the Green Climate Fund can play a very positive role to materialize compensations through technology-related projects.

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Ana Pueyo and Pedro Linares Renewable Technology Transfer to Developing Countries: One Size Does Not Fit All IDS WORKING PAPER, Volume 2012 No 412

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Appendices

1 Data sources

We gathered data from four main sources: the United Nations Commodity Trade Statistics Database, Bureau van Dijk's ORBIS database, the EPO/OECD World Patent Statistical Database, and the World Bank World Development Indicators.

1.2 Trade data

Trade data in US dollars comes from the United Nations COMTRADE database, which reports bilateral trade between countries at a highly disaggregated product level. Trade data in the COMTRADE database covers between 70% to 90% of world trade obtained from the WTO Statistics Database, depending on the year. As is the case with patent data, the very detailed classification system used in the COMTRADE database (a 6-digit classification of commodities) makes it possible to specifically identify trade in equipment goods that incorporate technologies to cut greenhouse gas emissions (for example wind turbines). We then measure technology transfer by the value of trade in these goods between trading partners.

1.2 Foreign investment data

To measure foreign direct investment, we rely on the financial database ORBIS, provided by Bureau Van Dijk under a commercial license. The ORBIS database includes firm-level data on investment stocks in foreign countries (due to mergers and acquisitions, creation of a subsidiary, etc.). In order to identify foreign direct investment by firms involved in sectors related to climate change, we have matched the ORBIS database with the PATSTAT database and identified companies which own at least one patent in climate-related technology. The rationale for this restriction is twofold. First, it makes it possible to provide an indicator of FDI at the technology level. Economic sector classifications available at the company level are too aggregated to allow for meaningful analyses at the technology-level. For example, we can only identify companies in the "Production of Electricity" sector, but cannot identify renewable energy producers. Second, it allows us to identify foreign investment that potentially involves the transfer of climate-friendly technology. This explains why patent and FDI statistics have the same technology scope (see below).

FDI data pose a specific challenge, as information on the volume of investments is frequently missing, in particular in developing countries. As an indicator of technology transfer, rather than measuring the volume of investment in 'country B' by companies located in 'country A', we use the number of capital links between companies in the source country and companies in the recipient country. This gives an indication of the intensity of capital links between country pairs.

1.3 Patent data

Patent data are drawn from the World Patent Statistical Database (PATSTAT) maintained by the European Patent Office. PATSTAT is the largest international patent database available to the research community with nearly 70 million patent documents included. Patent documents are categorized using the International Patent Classification (IPC) and national classification systems. This allows us to identify climate change mitigation technologies. In particular, we use the new "Y02" category developed by the European Patent Office to identify patents in PATSTAT pertaining to "technologies or applications for mitigation or adaptation against climate change". This new category is the result of an unprecedented effort by the European Patent Office, whereby patent examiners specialized in each technology, with the help of external experts, developed a tagging system of patents related to climate change mitigation technologies. The Y02 category provides the most accurate tagging method of climate change mitigation patents available today, and is becoming the international standard for clean innovation studies. We identify patents transferred internationally as patents filed by an inventor from a country different from that in which protection is sought, e.g., patents filed in the US by a German inventor.

1.4 Geographical coverage

Table 5 presents the geographical coverage of the data along with their time dimension. Geographical coverage is almost comprehensive for trade and FDI data: the COMTRADE database includes all 192 United Nations member countries and the ORBIS database gathers information from 197 countries. With 80 patent offices in PATSTAT, patent data is not as comprehensive, but they include the major patent offices in the world. Given the geographical coverage of the combined dataset, we can confidently consider that if some countries (in particular least-developed countries) do not appear across all three dimensions of the data set, the reason is that they do not participate in the international diffusion of technologies. There are, however, a few important exceptions: India, Indonesia, the Philippines, Vietnam, Pakistan, Bangladesh, Nigeria and Thailand.

Table 5. Geographical coverage of various data sources

	Definition	Data source	Geographical coverage	Period
International trade	Volume of bilateral trade of low-carbon equipment goods (in value)	COMTRADE	205 countries	1990-2009
Foreign direct investment	Number of subsidiaries in the recipient country owned by companies from the source country having at least one low-carbon patent	ORBIS	197 countries	2011
Patent flows	Volume of patents filed in the recipient country by inventors located in the source country	PATSTAT	80 patent offices Major exceptions : India, Indonesia, the Philippines, Vietnam, Pakistan, Bangladesh, Nigeria and Thailand	1990-2009

1.5 Technological scope

Our study covers a wide range of technologies across most sectors of the economy. Table 6 presents the precise technology coverage of the study. Obviously, not all technologies with a potential to mitigate climate change could be included in the analysis. The main reason is that their diffusion does not entail any patenting or international trade. This is the case for agriculture or forestry: technologies such as soil restoration, reforestation, rice or grassland management are simply not present in either trade or patent data. Another reason is that classifications used in trade and patent data do not allow us to identify some technologies, in particular technologies aiming at improving industrial energy efficiency. In practice, saving energy in the industrial sector mostly consists of using a more energy-efficient version of production equipment. It does not consist of adding a device which specifically saves energy in the production chain. The problem then is that patent or trade statistics are not detailed enough to distinguish between different versions of the same equipment. To give an example, the COMTRADE code 841780 describes “industrial/laboratory furnaces & ovens”, but no distinction is made between inefficient and energy-efficient furnaces. Nevertheless, the technologies in our data set represent 65% of the abatement potential until 2030 as identified in the McKinsey abatement curve.

Patent and FDI data offer the most extensive coverage: they are comprehensive for energy production (including cleaner coal). They are also very good for transport and energy efficiency in buildings (insulation, heating, and lighting). Data on energy efficiency in industry are more limited (except for aluminum and certain equipment goods in heavy industries). Trade data are not as comprehensive, because product classifications used to organize trade data do not offer the same level of disaggregation, as illustrated above.

Table 6. Technology fields included in the study

Technology group	Technology class	Patent flows	Trade flows	FDI
Renewables	Biofuels	X		X
	Fuel from waste	X		X
	Geothermal	X		X
	Hydro	X	X	X
	Marine	X		X
	Solar photovoltaic	X	X	X
	Solar thermal	X	X	X
	Wind	X	X	X
Nuclear	Nuclear	X	X	X
Combustion	Cleaner coal	X		X
Climate change mitigation	CCS	X		X
	Capture or disposal of non-CO2 GHG	X		X
Indirect contribution to mitigation	Energy storage	X	X	X
	Hydrogen technology	X		X
	Fuel cells	X		X
	Electricity distribution	X		X
Fuel efficiency transportation	Electric vehicles	X	X	X
	Hybrid vehicles	X	X	X
	Fuel efficiency in motors	X		X
	Fuel efficiency-improving vehicle design	X		X
	Rail locomotives powered by electric accumulators		X	
Energy efficiency in buildings	Energy efficient cement	X	X	X
	Heating	X	X	X
	Insulation	X	X	X
	Lighting	X	X	X
Energy efficiency in industry	Electric arc furnace for aluminum production	X		X
	Economizers, super-heaters, soot removers, gas recoverers		X	

2. Country groupings

LDC (Least Developed Countries)	Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Rep., Chad, Comoros, Dem. Rep. of the Congo, Djibouti, Equatorial Guinea, Eritrea, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Dem. Rep., Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Rep. of Tanzania, Vanuatu, Yemen, Zambia
OECD countries*	Australia, Austria, Belgium, Canada, Chile, Czech Rep., Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Rep. of Korea, Slovakia, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA
Emerging countries	Refers to Non-OECD countries that are not LDC

* Members in 2007