Invention and Transfer of Climate Change Mitigation Technologies on a Global Scale: A Study Drawing on Patent Data

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Executive summary

Accelerating the development of new less GHG intensive technologies and promoting their global diffusion—in particular in fast-growing emerging economies—is imperative in achieving the transition to a low-carbon economy. Consequently, technology is at the core of current discussions about the post-Kyoto regime.

The purpose of this study is to fuel this discussion by providing an in-depth analysis of the geographic distribution of climate mitigation inventions since 1978 and their international diffusion on a global scale. We use the EPO/OECD World Patent Statistical Database (PATSTAT) which includes patents from 81 national and international patent offices. Note that Least Developed Countries patent a negligible number of inventions, meaning that the geographical scope of the study is limited to industrialized countries and emerging economies.

In this study, patent counts are used to measure the output of innovation but also the transfer of inventions across borders on the ground that an innovator patents his/her invention in a foreign country because he/she plans to exploit it commercially there. They are the only indicator available today that provides a comprehensive view on innovation and technology diffusion on a global scale. Patent data also present drawbacks. First, patents are not the only tool available to inventors to protect their inventions. Second, successful technology transfers also involve the transfer of know-how. Still one can reasonably assume that patent counts are positively correlated to the quantity of non-patented innovations and transfers.

We consider 13 different classes of technologies with significant global GHG emission abatement potentials, and analyze inventive activities and international technology transfer between 1978 and 2003. The technologies considered are 6 renewable energy technologies (wind, solar, geothermal, ocean energy, biomass and hydropower), waste use and recovery, methane destruction, climate-friendly cement, energy conservation in buildings, motor vehicle fuel injection, energy-efficient lighting and Carbon Capture & Storage (CCS).

Impact of the Kyoto Protocol

Statistics suggest that the Protocol has induced more innovation in the recent period. While innovation in climate change technologies and innovation in all technologies were growing at the same pace until the mid-nineties, the former is now developing much faster. Between 1998 and 2003, innovation in climate mitigation technologies has been growing at the average annual rate of 9%. This increase has taken place in Annex 1 countries which have ratified the Kyoto Protocol but not in Australia and in the USA.

In contrast, there is no visible effect of the Kyoto protocol on technology transfer: international technology flows have been increasing in the recent period, but the growth rate is the same as the average.

Main inventor countries

Innovation in climate change technologies is highly concentrated in three countries—Japan, Germany and the USA—which account for two thirds of total innovations in the thirteen technologies. The performance of Japan is particularly impressive as it ranks first in twelve technology fields out of 13. In average it accounts for 40 percent of worldwide innovation.

Surprisingly, the innovation performance of emerging economies is far from being negligible as China, South Korea and Russia are respectively the fourth, fifth and sixth largest innovators. They globally represent about 15% of total inventions.

International technology diffusion

Do these new technologies cross national borders? The export rate—measured by the share of inventions that are patented in at least two countries—is around 25%. This sounds small, but it is only a few percent below the rate for all technologies. International transfers mostly occur between developed countries (75% of exported inventions). Exports from developed countries to emerging economies are still limited (18%) but are growing rapidly. This suggests a huge potential for the development of North-South transfers. Although China, Russia and South Korea are major innovators, flows between emerging economies are almost non-existent. Accordingly, there also exists a huge potential for South-South exchanges—particularly given that these countries may have developed technologies that are better tailored to the needs of developing countries.

Factors driving technology transfers

Finally we have run econometric regressions to identify the factors which promote or hinder the international diffusion of technologies. They show that absorptive capacities of recipient countries are determinant factors. This is particularly true for technology-specific knowledge whereas the general level of education exerts less influence. Concerning the impacts of policy barriers, the results stress that restrictions to international trade—e.g., high import tariff rates—particularly hinder the import of technologies. Lax intellectual property regimes also negatively influence the quantity of transfers, but only for a limited number of technologies. Barriers to Foreign Direct Investments also seem to have a limited influence. However these econometric results need to be confirmed by the use of more sophisticated models and should be considered with caution in the meantime.

1 Introduction

Accelerating the development of new low-carbon technologies and promoting their global application is a key challenge in stabilizing atmospheric GHG emissions. Consequently, technology is at the core of current discussions surrounding the post-Kyoto agreement. The 2007 Bali Road Map mentions technology development and diffusion as strategic objectives, thereby opening a debate on appropriate policies.

This debate is difficult in various respects. Environmentally-friendly technologies have been developed mostly in industrialized countries, but are urgently required to mitigate GHG emissions in fast-growing emerging economies. Ensuring their global diffusion thus implies considerable policy and economic challenges, as developing countries refuse to bear the financial costs of catching up alone, while firms in industrialized countries are reluctant to give away strategic intellectual assets. The problem is compounded by the lack of information. In the absence of a clear, widespread understanding of what constitutes a 'climate change mitigation technology', and also of how such technologies are diffused in the world, reaching consensus is a daunting task.

Against this background, the purpose of this paper is to shed light on the geographic distribution of climate mitigation inventions on a global scale. Using a worldwide patent database, we identify 13 different classes of technologies with significant global GHG emission abatement potentials, and analyze inventive activities and their international transfer between 1978 and 2003. More precisely, we consider 6 renewable energy technologies (wind, solar, geothermal, ocean energy, biomass and hydropower), waste use and recovery, methane destruction, climate-friendly cement, energy conservation in buildings, motor vehicle fuel injection, energy-efficient lighting and carbon capture & storage (CCS). Although we cover a wide range of climate-friendly technologies, note that key classes like clean coal technologies or electric vehicles have not been included due to data constraints. The technologies included in our data set represent nearly 50% of all GHG abatement opportunities beyond business as usual until 2030 — excluding forestry — identified by McKinsey & Company in the cost curve analysis carried out for Vattenfall AB (see Enkvist et al., 2007).

Although patents do not provide a measure of all innovation, they offer a good indication of the results of innovative activity and allow for interesting cross-country comparisons. Moreover, the database contains information from a large number of patent offices, and thus enables us to draw insights about international technology transfer.

To the best of our knowledge, this work is the first study using patent data to quantitatively describe the geographical and historical trend of innovation and diffusion of climate-mitigation technologies at global level. A paper by Lanjouw and Mody (1996) is the most closely related to our work. These authors focus on patents on environmentally responsive technology in Japan, Europe, the USA and fourteen developing countries. They identify the leaders in environmental patenting and find that significant transfers occur to developing countries. Our technology focus is on climate change and is therefore different, and our data are more recent and cover more countries.

Many papers study the development and transfer of non-environmental technologies. They usually rely on patent data from OCED countries, especially the USA. For example, Co (2002) studies the evolution of innovative activity across US States in 42 industrial sectors between 1963 and 1997. She finds that patent-lagging regions catch up with patent leaders and that knowledge diffusion between States is a significant determinant of patent growth. Using patent data—including citations—from Europe and the USA, Peri (2005) shows that knowledge diffusion reaches further than trade flows.

A different line of research investigates how patenting influences innovation and diffusion in an international context. In particular, it seeks to analyze the impacts of the TRIPS agreement which has reinforced intellectual property rights. Among other results, this literature highlights the fact that effective patent protection is a means to promote technology transfer towards developing countries that already have a certain level of technological capability (Maskus 2000; Smith 2001; Hoekman et al. 2004). Barton (2007) discusses from a legal perspective whether strong intellectual property rights in emerging economies would hinder or promote the transfer of "green" technology.

In this paper we advance well beyond this work. We use the EPO/OECD World Patent Statistical Database (PATSTAT) which includes patents from 81 national and international patent offices. This allows us—contrary to most studies focusing on a single patent office—to conduct a global analysis of innovative activity, including patents filed in developing countries. Moreover, it is the first time that indicators are constructed so that absolute cross-country comparisons can be made. We present the methodology that we implemented to limit biases stemming from the differences in propensity to patent across countries.

The study is organized as follows. Section 2 introduces the key concepts and discusses the use of patents as indicators of innovation and technology transfer. The dataset is presented in Section 3 along with data issues. In Section 4 we describe innovative activity in the world between 1978 and 2003, across different countries and technologies. Section 5 analyzes the international transfer of technologies. In Section 6, we present econometric regressions which aim to identify the factors driving the international transfer of technologies. A final section summarizes the main results.

2 Patents as indicators of innovation and technology transfer

In this section we justify the use of patents for measuring innovation and diffusion of climate-mitigation technologies. There are a number of possibilities for the measurement of innovation (see OECD *Main Science and Technology Indicators* 2008). Most commonly, R&D expenditures or the number of scientific personnel in different sectors are used. Although such indicators reflect an important element of the innovation system, there are a number of disadvantages associated with their use. For example, data on private R&D expenditures are incomplete. Furthermore, the data are only available at an aggregate level. Importantly, they are measures of inputs to the innovation process, whereas an "output" measure of innovation is broadly preferable.

By contrast, patent data focus on outputs of the inventive process (Griliches 1990). They provide a wealth of information on the nature of the invention and the applicant. Most importantly, they can be disaggregated to specific technological areas. Finally, they indicate not only the countries where inventions are made, but also where these new technologies are used. These features make our study of climate mitigation technologies possible. Of course they present drawbacks which we will discuss below.

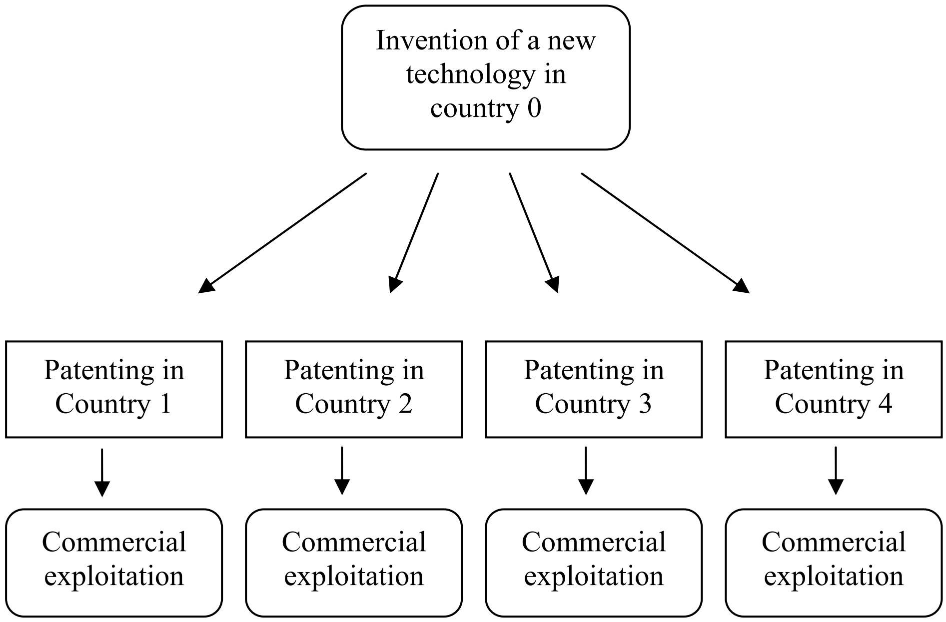
In order to give a more precise view of our indicators, it is necessary to briefly recall how patenting works. Figure 1 depicts a simplified innovative process. In the first stage, an inventor from country 0 discovers a new technology. He then decides to patent the new technology in certain countries. A patent in country i grants him the exclusive right to commercially exploit the innovation in that country. Accordingly, the inventor patents his invention in a country i if he plans to use it there. The set of patents related to the same invention is called a patent family. The vast majority of families include only one country (often that of the inventor, particularly for large countries).

In this paper we use the number of families as an indicator of the number of inventions and the number of patents invented in country 0 and filed in country i as an indicator of the number of innovations transferred from country 0 to country i.

These indicators are only imperfect proxies. A first limit is that patents are only one of the means of protecting innovations, along with lead time, industrial secrecy or purposefully complex specifications (Cohen et al. 2000; Frietsch and Schmoch 2006). In particular, inventors may prefer secrecy to prevent the public disclosure of the invention imposed by patent law, or to save the significant fees attached to patent filing. However, there are very few examples of economically significant inventions which have not been patented (Dernis and Guellec 2001).

Importantly, the propensity to patent differs between sectors, depending on the nature of the technology (Cohen et al. 2000). It also depends on the risk of imitation in the country. Accordingly, patenting is more likely to concern countries with technological capabilities and a strict enforcement of intellectual property rights. In this study we have developed a method which partly controls for this problem.

Figure 1. The innovative process



A further limit is that a patent grants only the exclusive right to use the technology in a given country. It does not mean that the patent owner will actually do so. This could significantly bias our results if applying for protection does not cost anything, so that inventors might patent widely and indiscriminately. But this is not the case in practice. 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 (see Helfgott 1993 and Berger 2005 for EPO applications). Moreover, if enforcement is weak, the publication of the patent in the local language can increase vulnerability to imitation (see Eaton and Kortum 1995 and 1999). Therefore, inventors are unlikely to apply for patent protection in a country unless they are relatively certain of the potential market for the technology covered.

However, the fact remains that the value of individual patents is heterogeneous. Moreover, its distribution is skewed: as many patents have very little value, the number of patents does not perfectly reflect the value of innovations. Methods have been developed to mitigate this problem (see Lanjouw et al. 1998), for instance, the use of weights based on the number of times a given patent is cited in subsequent ones. Unfortunately our data do not allow us to implement these methods.

3 Data description

Over the past several years, the OECD's Directorate for Science, Technology and Industry, jointly with the European Patent Office (EPO), have developed a worldwide patent database—the EPO/OECD World Patent Statistical Database (PATSTAT). PATSTAT is unique in that it covers more than 80 patent offices and contains over 70 million patent documents. It is updated bi-annually. Patent documents are categorized using the international patent classification (IPC) and national classification systems. In addition to the basic bibliometric and legal data, the database also includes patent descriptions (abstracts) and harmonized citation data. PATSTAT data have not been exploited much until now for they became available only recently. Our study is the first to use PATSTAT data pertaining to climate change.

We have extracted all the patents filed from 1978 to 2003 in 13 climate-mitigation fields[1]: 6 renewable energy technologies (wind, solar, geothermal, ocean energy, biomass and hydropower), waste use and recovery, methane destruction, climate-friendly cement, energy conservation in buildings, motor vehicle fuel injection, energy-efficient lighting and carbon capture & storage (CCS). The precise description of the fields covered by the study can be found in Table 1. This represents 273,900 patent applications filed in 76 countries. On average, climate-related patents included in our data set represent 1% of the total annual number of patents filed worldwide.

Building a patent data set requires many problems to be solved, particularly when data are subsequently used in cross-country comparisons. We now describe these problems and the way we have tried to deal with them in this study. We frequently leave details in appendices.

Patent applications related to climate change are identified using the International Patent Classification (IPC) codes, developed at the World Intellectual Property Organization (WIPO)[2]. The IPC classes corresponding to the climate mitigation technologies are identified in two alternative ways. First, we search the descriptions of the classes online to find those which are appropriate[3]. Second, using the online international patent database maintained by the European Patent Office[4], we search patent titles and abstracts for relevant keywords. The IPC classes corresponding to the patents that come up are included, provided their description confirms their relevancy.

When building the data sets, two possible types of error may arise: irrelevant patents may be included or relevant ones left out. The first error happens if an IPC class includes patents that bear no relation to climate mitigation. In order to avoid this problem, we carefully examine a sample of patent titles for every IPC class considered for inclusion, and exclude those classes that do not consist only of patents related to climate-mitigation. This is why key technologies in terms of carbon reduction potential are outside the scope of this study. Important missing technologies include electric vehicles, energy efficient technologies in industry, or clean coal technologies.

The second error—relevant inventions are left out—is less problematic. We can reasonably assume that all innovation in a given field behaves in a similar way and hence our datasets can be seen at worst as good proxies of innovative activity in the field considered. However, overall innovative activity may be underestimated and totals may be less reliable than trends.

The definitions of the IPC codes used to build the datasets can be found in Annex 1. The number of applications by technology field can be found in Annex 2.

We also deal with the issue of patent breadth. It is well known among experts in intellectual property rights that the number of patents that is granted for a given innovation varies significantly across countries. A usual illustration is Japan where patent breadth is said to be particularly low.

We consider this problem by examining international patent families. Recall that each family corresponds to a particular innovation. The study of international families yields information on the number of patents in the countries where the innovation is patented. We use this information to calculate country weights. As an illustration, we found that, on average, seven Japanese patents result in approximately five European patents when filed at the EPO. This means that one EPO patent is equivalent, on average, to 1.4 Japanese patents. We randomly set the weight of applications at the EPO to unity, meaning that the statistics presented below yield the number of 'EPO-equivalent' inventions. The EPO-equivalent country weights for various patent offices are available in Annex 3.

Other specific problems concern patents in the US, where until 2000 the data concern only *granted* patents, while other offices provide data on *applications*. Patent counts in Europe also involve specific difficulties because of the procedural specificities of the European patent system. Finally, the inventor's country of residence is not available for some patent applications. Annex 4 presents details on how we solve these problems.

Table 1. Description of the technology fields covered

Technology field	Description of aspects covered
Biomass	Solid fuels based on materials of non-mineral origin (i.e. animal or plant); engines operating on such fuels (e.g. wood).
Buildings	Elements or materials used for heat insulation; double-glazed windows; energy recovery systems in air conditioning or ventilation.
CCS	Extraction, transportation, storage and sequestration of CO2
Cement	Natural pozzuolana cements; cements containing slag; iron ore cements; cements from oil shales, residues or waste; calcium sulfate cements.
Fuel injection	Motor fuel-injection apparatus (allowing reduced fuel consumption)
Geothermal	Use of geothermal heat; devices for producing mechanical power from geothermal energy.
Hydro	Hydro power stations; hydraulic turbines; submerged units incorporating electric generators; devices for controlling hydraulic turbines.
Lighting	Compact Fluorescent Lamps; Electroluminescent light sources (LED)
Methane	Equipment for anaerobic treatment of sludge; biological treatment of waste water or sewage; anaerobic digestion processes; apparatus aiming at collecting fermentation gases.
Ocean	Tide or wave power plants; mechanisms using ocean thermal energy conversion; water wheels.
Solar	Solar photovoltaic (conversion of light radiation into electrical energy), incl. solar panels; concentrating solar power (solar heat collectors having lenses or reflectors as concentrating elements); solar heat (use of solar heat for heating & cooling).
Waste	Solid fuels based on waste; recovery of heat from waste incineration; production of energy from waste or waste gasses; recovery of waste heat from exhaust gases.
Wind	Wind motors; devices aimed at controlling such motors.

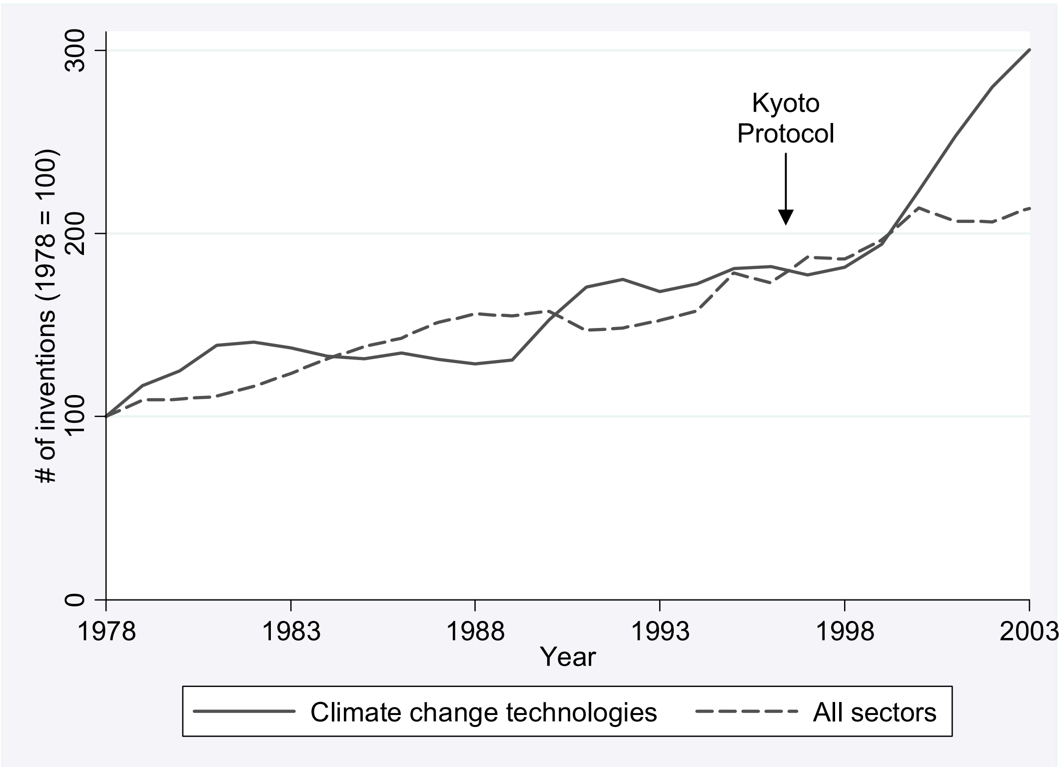
4 Descriptive statistics on innovation

In this section we discuss the level of innovation outputs across technologies and countries, and the time trend over the period 1978-2003.

General figures

The average number of inventions is about 7,300 per year in the last 6 years of our dataset (1998-2003). The innovation trend since 1978 is depicted in Figure 2. As a benchmark, we also represent the evolution of the annual number of inventions in all sectors. The graph clearly shows that while the trend for climate-friendly technologies was not specific until the end of the nineties, the growth rate is now much higher than the global rate. This suggests a significant influence of climate change policies since the signing of the Kyoto protocol in 1997.

Figure 2: Innovation trend in climate technologies* compared to all sectors



* The count of climate-friendly technologies is not the arithmetic sum of inventions of the different technology classes. We have normalized the counts so as to give identical weights to each technology field.

This is reinforced by Figure 3 which compares innovation performance of Annex 1 countries, which have ratified the Kyoto protocol, with the USA and Australia, which have not.

Figure 3: Innovation trend in Annex 1 countries

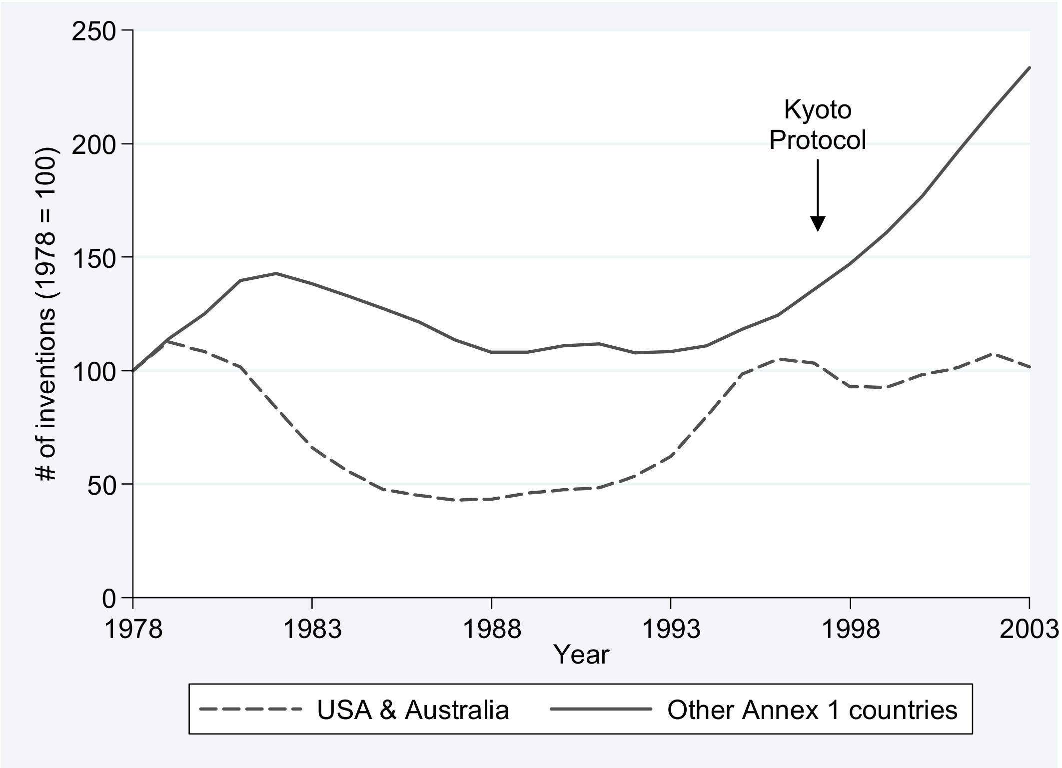
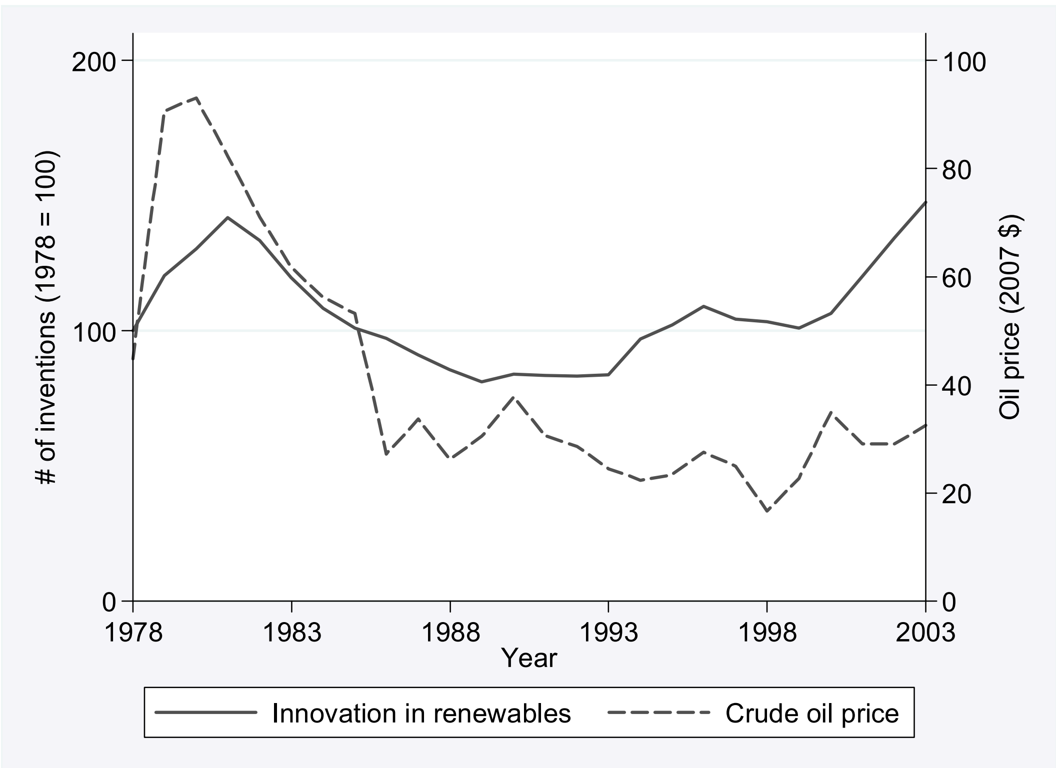


Figure 4: Innovation in renewable energy technologies between 1978 and 2003, in comparison with oil prices



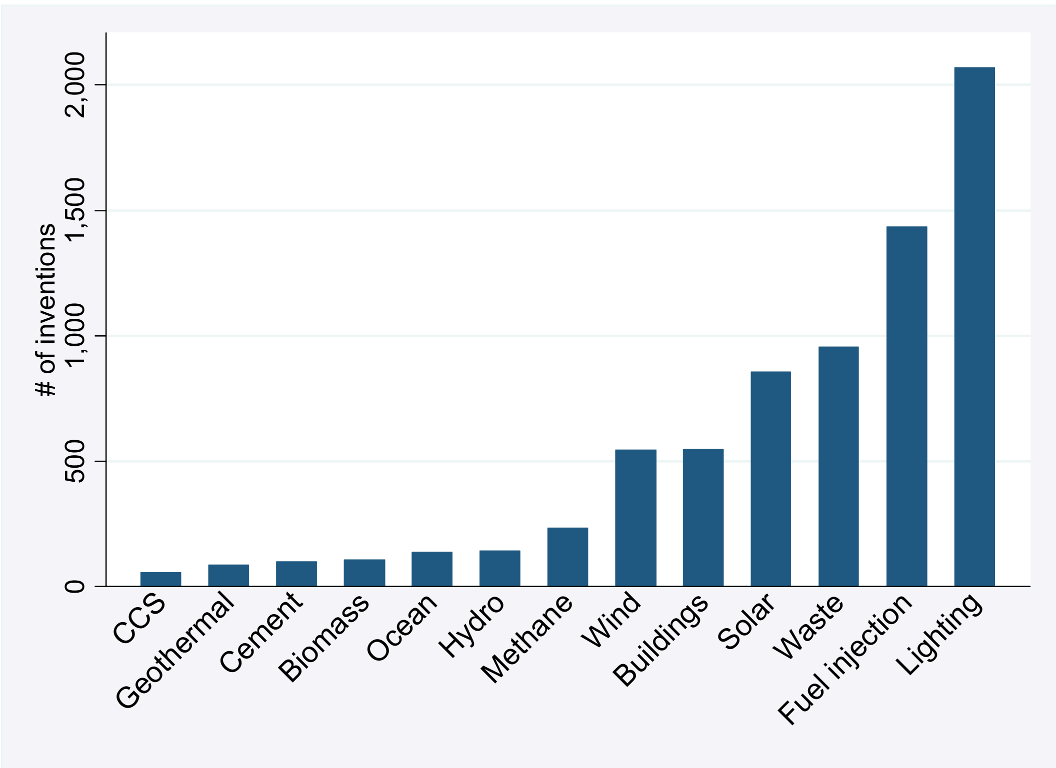
In specific areas, the evolution of oil prices seems to have had a significant influence. As shown in Figure 4, this is the case of renewable energies. Note that the level of innovation in 2003 just equals the early 1980s record high in this area.

Innovation by technology

We now consider the different technology classes. Recall that patent breadth varies across sectors and that we have controlled only for cross-country heterogeneity. As a result, observed differences between technologies may reflect differences either in patent breadth or in innovation outputs.

Keeping this important limit in mind, Figure 5 below shows that the recent level of innovation output differs widely across technologies. *Lighting* and *fuel injection* are clearly dominant, with about 2,000 and 1,500 inventions per year, respectively. This corresponds to large R&D-intensive industries where patents are perceived as an efficient means of protection (Cohen et al. 2000). By contrast, *CCS*, *geothermal*, *cement*, *biomass*, *ocean*, *hydro* and *methane* have fewer than 500 inventions per year over the same period. This group is heterogeneous. *Biomass*, *hydropower* and *geothermal energy* have already reached maturity whereas *ocean energy* and *CCS* are currently in the early development stages.

Figure 5: Average number of annual patented inventions 1998-2003, by technology



What about trends since 1978? To answer the question, we have used as a benchmark the growth of inventions that are technically similar to the technology classes of interest, without necessarily being related to the environment. The sectoral benchmarks reflect the growth of patenting activity in electricity production, motor vehicles, buildings, cement and lighting. The IPC codes that we used for these benchmarks can be found in Annex 5.

Table 2 shows the difference between the growth rate of innovation for each technology between 1978 and 2003, and the growth rate in the sectoral benchmarks. Carbon capture and storage is a new field with very few inventions and is treated separately.

Innovative activity in climate-change related technologies increased faster than in the corresponding benchmark in 5 fields out of 12. The growth of innovation is particularly strong in *lighting, waste*, *wind*, *biomass* and *methane*, whereas it is weak in the *ocean*, *solar*, *hydro* and *geothermal* classes. This result could be expected in the case of mature technologies such as *hydro* and *geothermal,* but is more surprising in the case of *solar* and *ocean*. Interestingly, the growth of innovation in *fuel injection* systems is also lower than that of the motor vehicle sector as a whole.

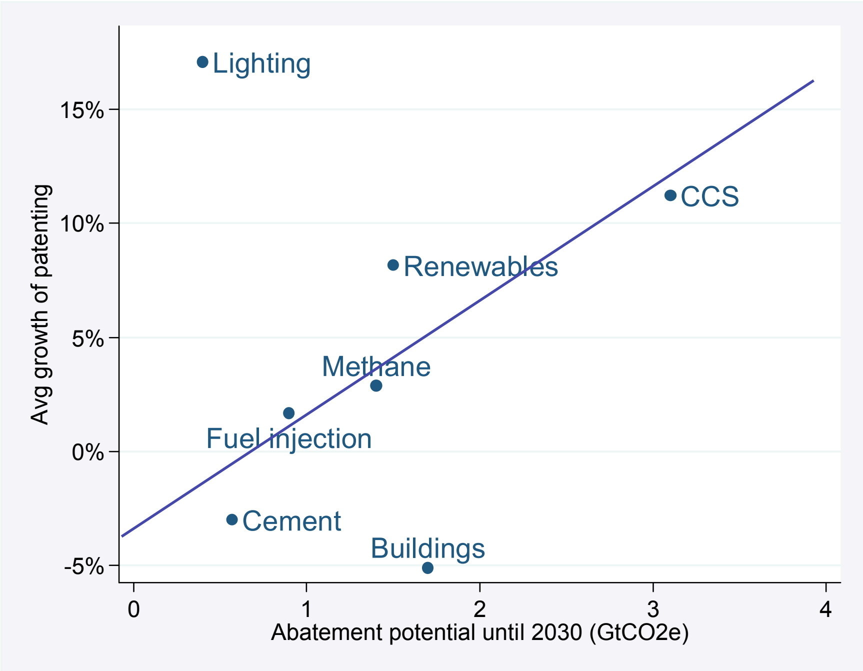
The evolution of all technology fields between 1978 and 2003 is shown in Annex 6.

Table 2: Growth of innovation by technology between 1978 and 2003, in comparison with relevant benchmarks

Technology	Growth 1978-2003	Growth of associated benchmark 1978-2003	Difference in growth rates (percentage points)
Biomass	+ 134%	+40%	+94
Buildings	+50%	+77%	-27
Cement	-14%	+46%	-60
Fuel injection	+174%	+226%	-52
Geothermal	+32%	+40%	-8
Hydro	-5%	+40%	-45
Lighting	+609%	+283%	+326
Methane	+253%	+114%	+139
Ocean	-29%	+40%	-69
Solar	-25%	+40%	-65
Waste	+760%	+114%	+646
Wind	+231%	+40%	+190

Are these innovation efforts in line with future needs? Figures 6 relates the average level of patenting in the recent period to the potential of abatement by 2030, i.e. the quantity of GHG emissions that can be avoided at the global level at a cost below 40 €/tCO2e. This graph suggests that innovation is in line with future abatement potential However, the graph highlights the specificity of *lighting* on the one hand and of *buildings* on the other. It suggests that innovation would be too limited in the *buildings insulation* sector.

Figure 6: Average annual growth rate of patenting 1998-2003 and global GHG abatement opportunities up to 2030



Note: abatement potential until 2030 with a cost below 40 €/ton of avoided CO2e emissions
Source: McKinsey / Vattenfall analysis & authors' calculations

Leading inventor countries

Where do innovations take place? The PATSTAT database includes information on the country of residence of patent applicants, independently of the country where applications are filed. We use this indicator to measure the performance of inventor countries.[5]

Table 3 displays the main inventor countries between 1998 and 2003. Japan, the USA and Germany are the three main inventors in most technologies (details on the top 3 inventors for each technology can be found in Annex 7). With more than 40% of the world's inventions on average, the performance of Japan is particularly impressive. It ranks first in all fields, except in *biomass* where it is second. In terms of percentage, Japan accounts for over 50% of the world's innovations in *methane*, *waste* and *lighting*.

This is consistent with available evidence on R&D activity. In the absence of detailed data on private R&D, available figures on public R&D for low-carbon technologies[6] confirm the strong leadership of Japan: with $US 220 million spent in 2004, Japan alone outweighs the sum of US and EU15 public R&D spending (respectively $US 70 million and $US 50 million in 2004).

Interestingly, the three world's leaders are followed by China, South Korea and Russia. Surprisingly, some emerging countries are already major innovators. As shown in Annex 7, these countries have strong positions in particular fields, namely *geothermal* and *cement* (China and Russia), *biomass* (South Korea) and *CCS* (Russia).

Together, EU27 countries represent 24% of innovation.

Table 3: Top 10 inventors, with average % of total inventions (1998 - 2003)

Country	Rank	Average % of world inventions	Most important technology classes (decreasing order)
Japan	1	40.8 %	All technologies
USA	2	12.8 %	Wind, solar, hydro, methane, buildings
Germany	3	12.7 %	Biomass, Ocean, Waste, CCS, wind, solar
China	4	5.8 %	Cement, geothermal, solar, hydro, methane
South Korea	5	4.6 %	Lighting, ocean, hydro, biomass, cement
Russia	6	4.2 %	Geothermal, cement, hydro, CCS, ocean
France	7	2.4 %	Cement, CCS, buildings, biomass, hydro
UK	8	1.9 %	Ocean, biomass, wind, methane
Canada	9	1.5 %	Hydro, wind, CCS, ocean
Brazil	10	1.1 %	Ocean, building

Table 3 suggests that the production of innovation in climate-related technologies is strongly concentrated in a limited number of inventor countries. For a more synthetic view, we calculate an index based on the countries' shares in the world patented inventions. The index is equal to:

$$H = \sum_{i=1}^{n} s_i^2$$

where s_i is the share of inventions patented by country i, and n is the number of countries. This index is directly adapted from the so-called Herfindahl-Hirschman Index (HHI) which is commonly used by antitrust authorities to measure the concentration in markets. Above 0.2, it characterizes a strong concentration; below 0.1, it denotes a weak concentration.

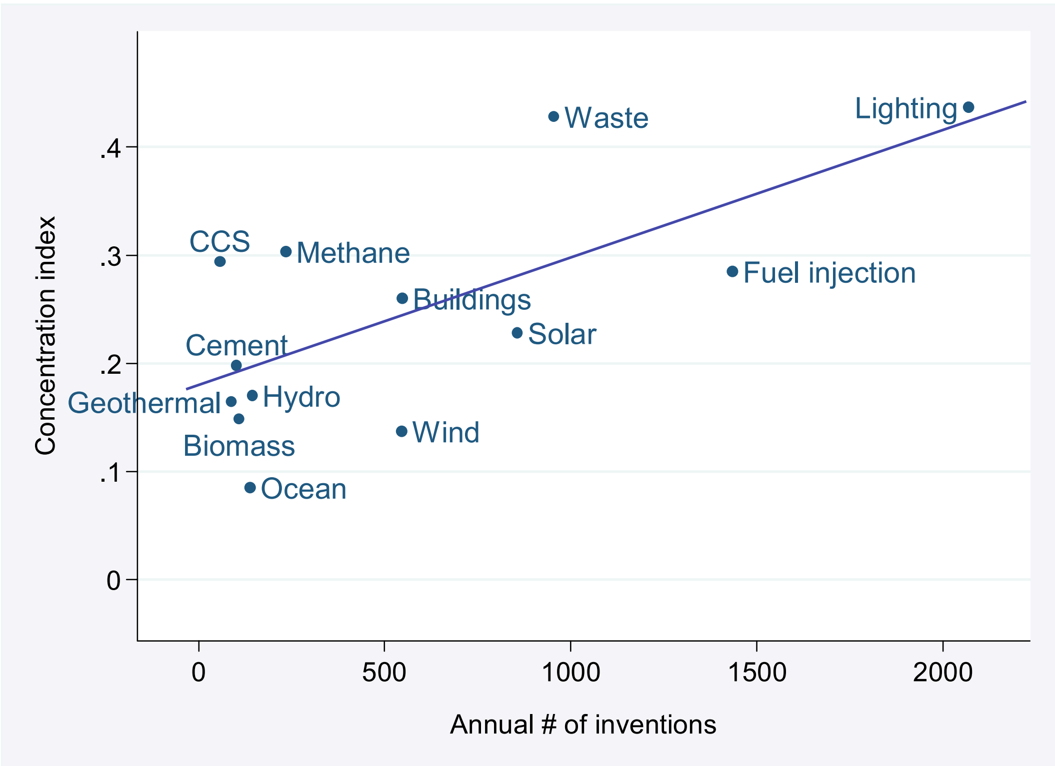
Table 4 presents this index for each technology. We have used the standard threshold of 0.2 to sort out the technology classes for which innovation is highly concentrated. This approach highlights contrasting degrees of concentration across technologies.

Table 4: Spatial concentration of innovation for each technology (1998 - 2003)

Strong concentration	Index	Mild concentration	Index
Lighting	0.437	Cement	0.198
Waste	0.428	Hydro	0.170
Methane	0.303	Geothermal	0.164
CCS	0.294	Biomass	0.148
Fuel injection	0.285	Wind	0.137
Buildings	0.260	Ocean	0.085
Solar	0.228		

Interestingly, technology classes exhibiting a high concentration index also seem to be those with the highest innovation outputs. Figure 7 represents the concentration index as a function of the volume of innovation and confirms this positive correlation. This suggests the existence of specialization gains which enable certain countries to benefit from comparative advantages in certain technology fields.

Figure 7: Concentration indices as a function of the annual innovation flow by technology

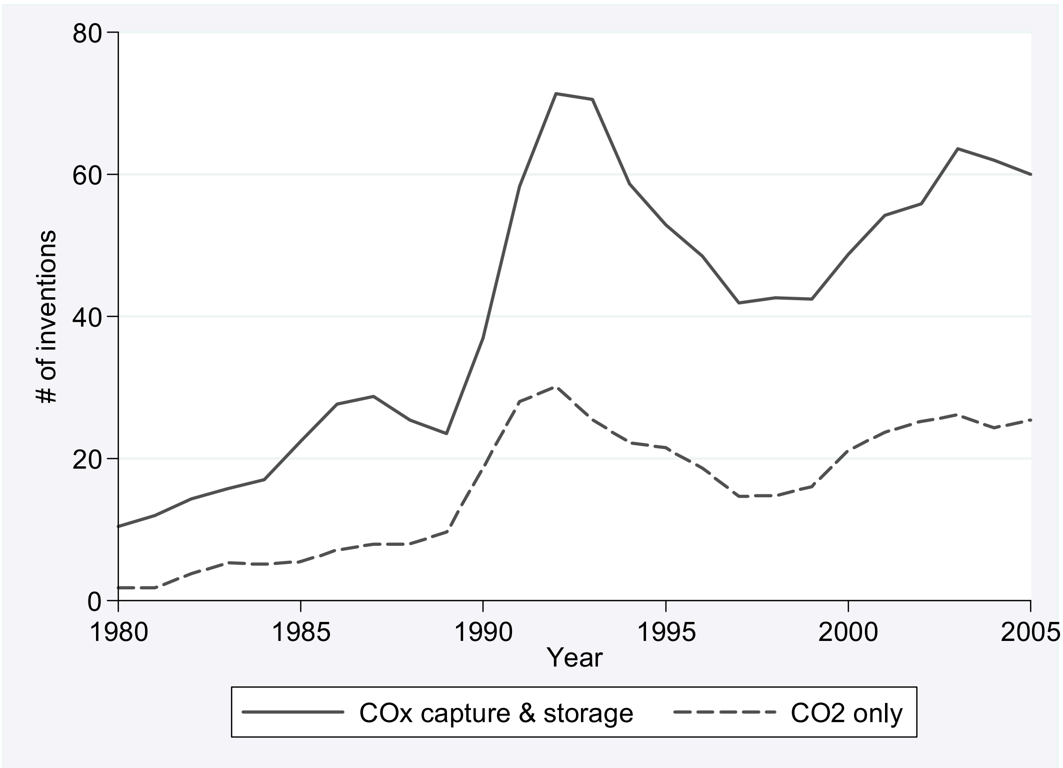


A focus on Carbon Capture and Storage

Given the potentially huge importance of CCS in the medium term, we consider it relevant to dedicate a specific subsection to these technologies. Identifying patent applications related to carbon capture and storage is difficult since there is no IPC code corresponding precisely to CCS inventions. However, IPC class B01D53 includes inventions relative to "chemical or biological purification of waste gases". We extracted all patents belonging to the B01D53/62 sub-class which concerns carbon oxides, and identified patents dealing specifically with carbon dioxide. To this data set we added patents found through a keyword search on titles—thus biased towards patents published in English. We searched for titles mentioning "capture", "storage" or "sequestration" together with "CO_2" or "carbon dioxide". This database is a good proxy of innovative activity in CCS.

Figure 8 displays the number of yearly inventions in CCS technologies from 1980 to 2005. The solid line includes all patents in the data set and the dashed line includes only patents specifically dealing with CO2. Surprisingly, the annual number of inventions increased steeply in the late 1980s, reaching a peak in 1992, before falling for about 5 years. Since 1997 the level of innovation has been increasing gradually, but in 2005 it was still below the 1992 record high. According to our data set, between only 25 and 60 inventions sought legal protection in 2005.

Figure 8. Patented innovation in carbon capture & storage, 1980-2005



Note that we probably underestimate the actual rate of innovation, since many inventions designed to isolate, transport and store gases are likely to have potential applications for CO_2. However, our data shows that there are still very few inventions with specific CO_2 capture & storage applications.

Between 2000 and 2005, Japan accounted for over half of all inventions, followed by the US, which has been particularly active in the late 1990s and early 2000s. Other countries such as France, Russia and UK are also starting to emerge as significant sources of invention.

A focus on emerging economies

We have already seen that certain emerging countries—China, Russia, and South Korea in particular—are performing well in certain areas (*geothermal*, *cement*, *biomass*). Apart from these countries, what is the overall picture? Table 5 displays statistics on selected emerging countries.[7] It clearly shows that China, South Korea and Russia are the only significant innovators in this group of countries.

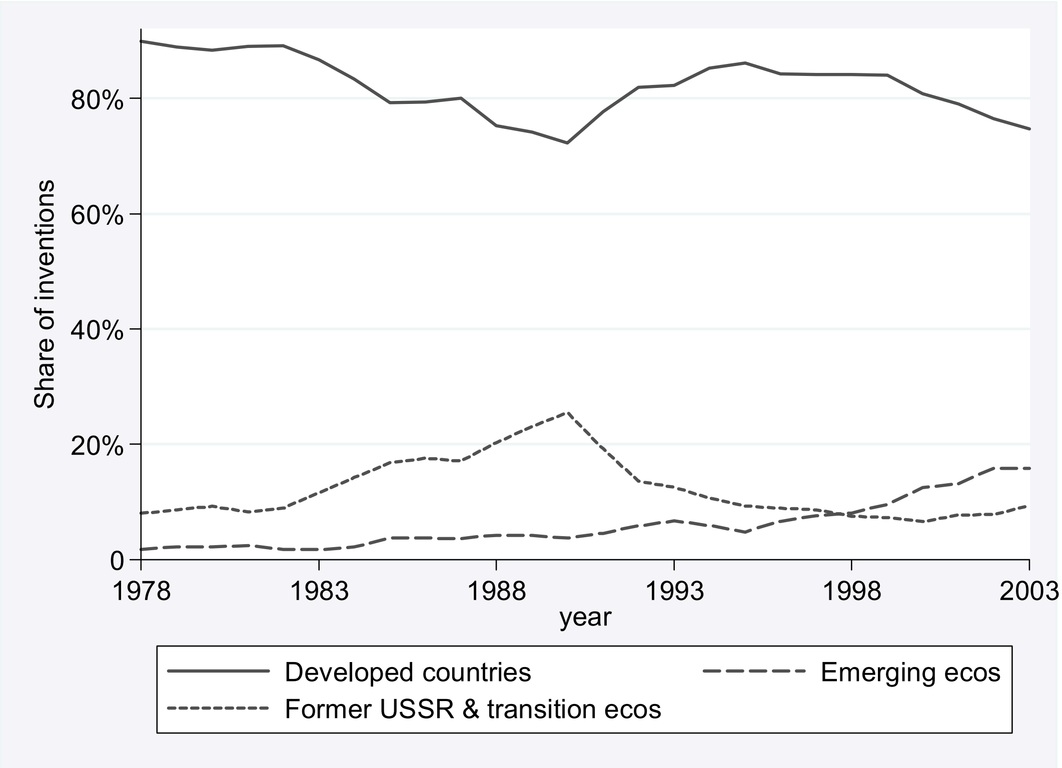
Table 5: Averages of the share of world innovations in each technology field for selected emerging economies (1998-2003)

	World rank	Average % of world inventions	Most important technology classes (decreasing order)
China	4	5.8 %	Cement, geothermal, solar, hydro, methane
South Korea	5	4.6 %	Lighting, ocean, hydro, biomass, cement
Russia	6	4.2 %	Geothermal, cement, hydro, CCS, ocean
Brazil	10	1.1 %	Ocean, building
Taiwan	18	0.6 %	Ocean, lighting
India	30	0.2 %	Cement
Mexico	34	0.1%	Ocean
South Africa	53	0.03%	

Emerging countries accounted for 16.3% of patented climate-friendly innovations in 2003. As shown in Figure 9, this is the result of a continuous increase which accelerated in the mid-nineties. Between 1997 and 2003, the share of inventions patented by emerging countries grew at an average annual rate of 18%. Additional figures on the growth of innovation in emerging countries for each technology field can be found in Annex 9.

The case of the former USSR and the transition economies is also very interesting. Before 1990, the Soviet Union and its satellite countries were steadily catching up with developed countries. Their innovative output then fell dramatically after the collapse of the Soviet Union.

Figure 9: Share of inventions by inventor country groups (1978 - 2003)



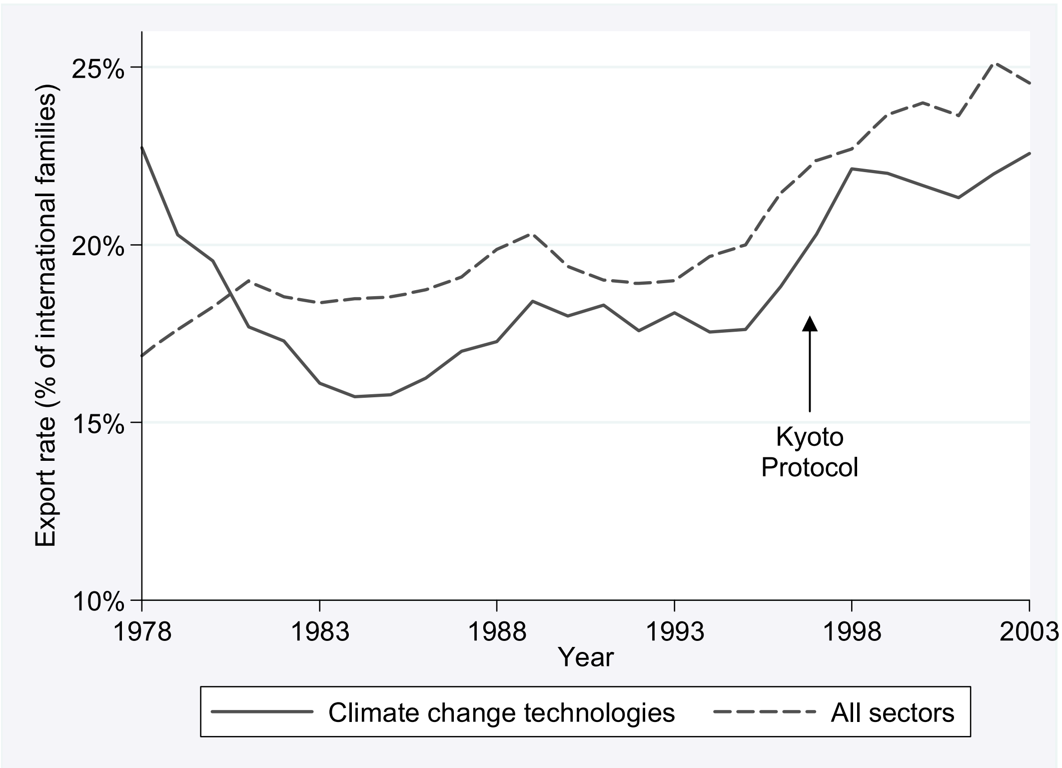
The list of countries included in each group can be found in Annex 8.

5 International technology transfer

We now study where inventions are used and in particular whether they cross national borders. International patent families provide interesting indicators of the international transfer of technologies. Inventors who want to enter markets in foreign countries usually seek patent protection in these countries for their most valuable innovations. We use the proportion of international families—the share of inventions that are patented in at least two countries—to measure the degree of internalization of markets for technology. At the country level, a large share of international families among inventions developed by domestic inventors denotes a good performance in terms of technology exports.

Figure 10 shows the export rate of climate change technologies between 1978 and 2003. As a benchmark we report in the same graph the evolution for all technologies. The export rate varied significantly over the period. It decreased sharply between 1978 and 1984 – possibly after a peak due to the 1979 oil crisis which temporarily increased the international demand for energy-efficient technologies—and then increased until 2003.

Figure 10: Percentage of international families, 1978-2003.



Although this trend marks a real progression of technology internationalization since 1983—from 16% of inventions to 23% in 2003 –, the export rate in 2003 only equals its 1978 value. This sounds very modest. However, the graph shows that it is not that much lower than the rate for all technologies. Furthermore, unlike the case of innovation, the signature of the Kyoto Protocol does not seem to have had a significant impact on the international diffusion of climate mitigation technologies as compared to the overall trend in all sectors.

The geography of international technology flows

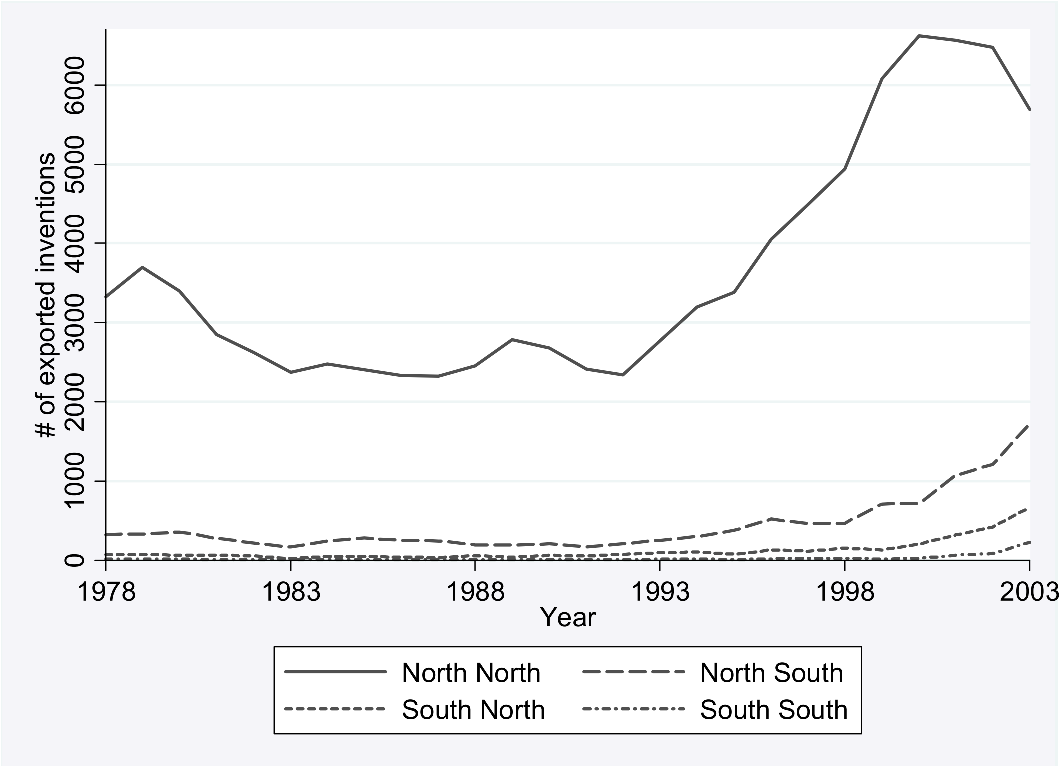
The PATSTAT database identifies the inventor countries—the countries of residence of the inventors—and the recipient countries—the countries where the invention is patented. We define an exported invention as a patent granted to an inventor from a country different from that in which protection is sought, e.g. a patent filed in the US by a German inventor.

Table 6 gives the origin and destination of the inventions exported in the period 1998-2003. Clearly, international transfer essentially concerns the developed countries. North-South transfer accounts for less than 15 % of all exported inventions. South-South transfers are almost non-existent. Nevertheless, Figure 11 shows that this has been evolving very quickly since the end of the nineties.

Table 6: Origin-Destination matrix giving the average annual number of exported inventions from 1998 to 2003 (% in brackets)

Destination / Origin	Developed countries	Emerging & transition economies
Developed	5812 (75.9 %)	1360 (17.8 %)
Emerging & transition economies	377 (4.9 %)	112 (1.5 %)

Figure 11: International trends in technology flows, 1978-2003.



In this graph, "North" countries are Annex 1 countries and "South" countries are non-Annex 1

International transfer by technology

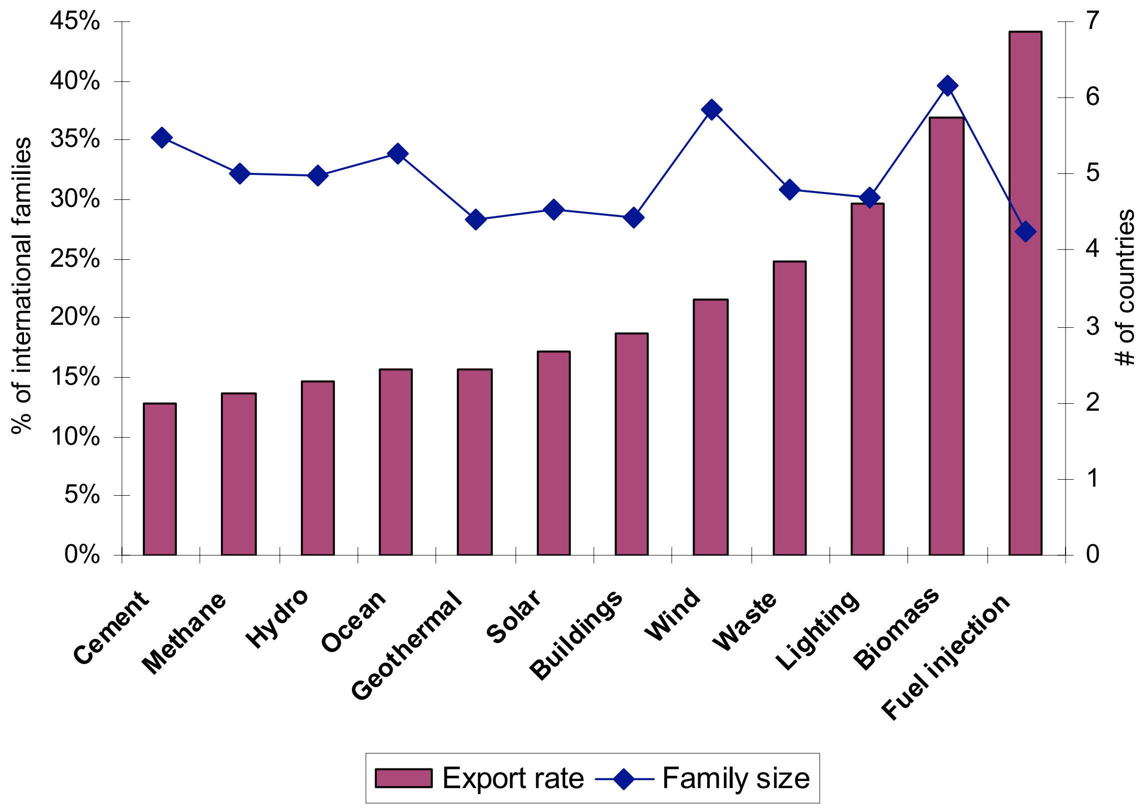
Figure 12 below displays the export rate, as measured by the percentage of international families, by technology. It differs substantially between technology classes (from 13% to 45%) and tends to reflect the level of maturity of each class.

The most internationalized technology classes are *fuel injection* (45%), *biomass* (37%) and *lighting* (30%). The *fuel injection* and *lighting* classes correspond to internationalized industries that invest heavily in R&D (as shown in Figure 5). The case of *biomass* is different, since the global number of patented innovations is much lower in this mature renewable energy technology class. This suggests an original pattern of modest but strongly internationalized innovation.

The less internationalized technologies (*cement*, *methane*, *hydro*, *ocean*, *geothermal*) are also those with the lowest numbers of inventions. These features denote limited inventive activity taking place mainly on a local scale. Besides *cement*, they concern either mature (except, again, biomass) or emerging renewable energy technologies.

The average size of international families, as measured by the number of countries where patent protection is asked for, provides information on the size of the markets targeted by patent owners. In contrast to export rates, the size of international families is relatively constant among technology fields: on average, exported inventions are patented in about 5 countries, with peaks at 6 for *wind* and *biomass*. This suggests that the size of the international market for technology (as measured by the number of countries where patent protection is sought) does not vary significantly across technology fields. The most frequent family members are the US, Germany, Japan, Austria and Spain.

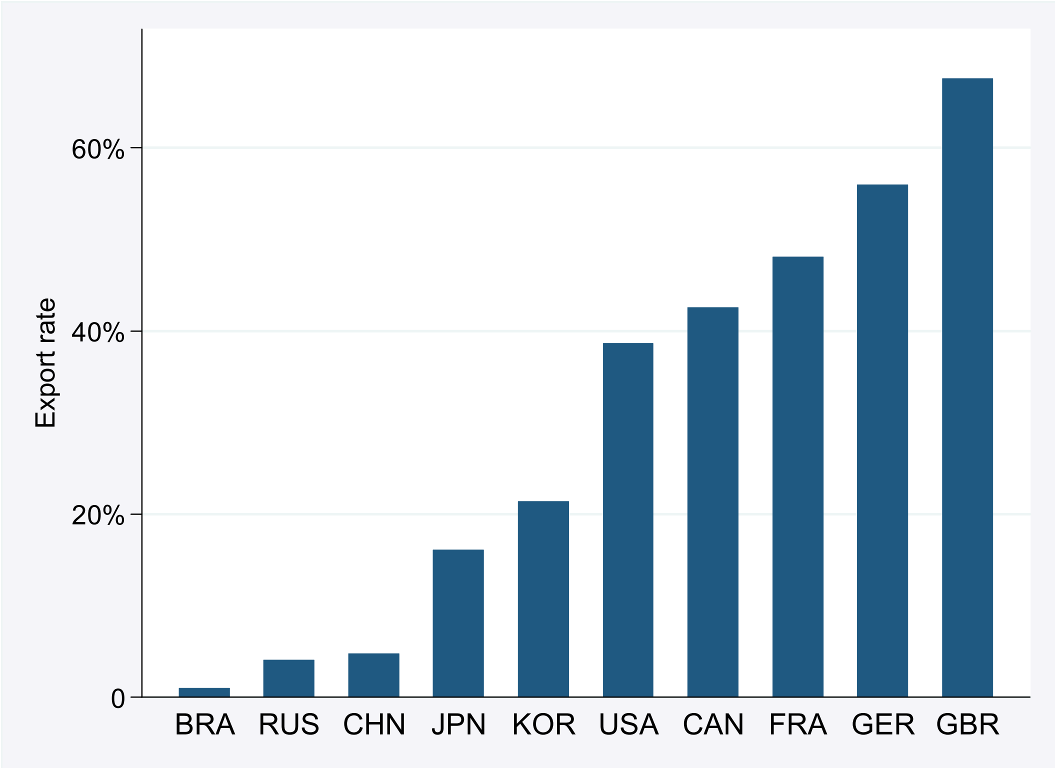
Figure 12: Export rate and size of international families by technology (1998-2003)



Exporting countries

Figure 13 shows the rate of export for the 10 main inventor countries presented in Table 3. The countries are displayed according to their ranking as inventor, in decreasing order from left to right. Interestingly, export rates vary widely across countries and the main innovators are not necessarily the best exporters. More than half of German inventions are exported. But the export rate is below 20% for Japan. More generally, Figure 13 shows very good performances of western countries (Germany, France, the USA, Canada and the UK). By contrast, emerging economies—with the exception of South Korea— export much less.

Figure 13: rate of exports for the 10 main inventor countries (1998-2003)



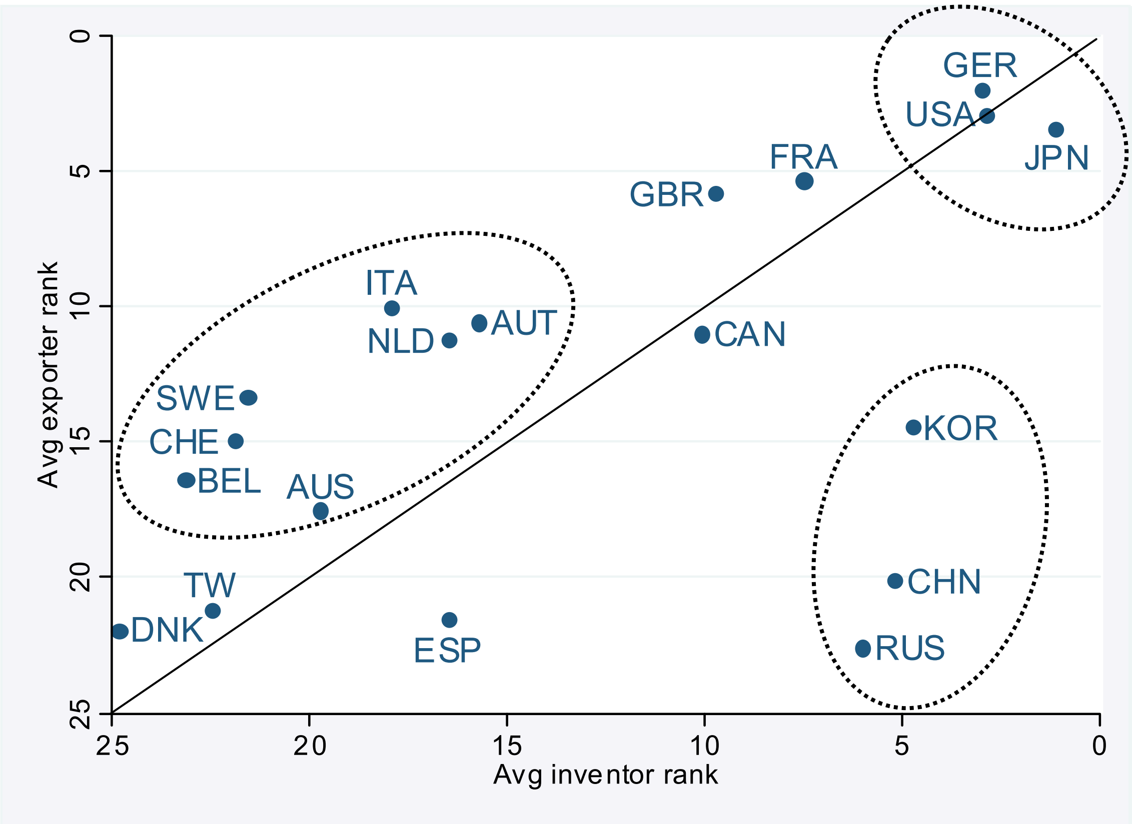
Note: the export rate of inventions is the percentage of inventions that have been patented in at least one country other than the inventor's country

In Figure 14, we seek to compare the countries' performances in terms of innovation and technology exports countries. The graph represents each according to their average ranking as inventor and as technology exporter in each technology field. The observations suggest a positive link between invention and exports, but also highlight important differences between three categories of countries.

In the top right corner, Japan, the USA and Germany stand out as world leaders in both innovation and exports. On the left-hand side, a group of medium-sized European economies have excellent performances in terms of technology exports, given their limited contributions to world inventions. This suggests that inventors in these countries are strongly oriented towards international markets.

By contrast, emerging economies such as China, South Korea and Russia have good innovative performances in some technologies (especially in *geothermal*, *cement* and *lighting*), but scarcely export their inventions. Inventors in these countries seem to focus primarily on local markets, either because their inventions mostly address local needs or because they lack the resources to export their technologies.

Figure 14: Countries' performances in invention and technology exports (1998-2003)



Note: the country codes are available in Annex 10.

Importing or innovating?

We define technology imports in a country as the foreign inventions that are patented in that country. As regards imports, a key question is whether they crowd out local innovations. Figures 15 and 16 allow us to answer that question. They unambiguously show that the volume of imports is positively correlated to the volume of local innovations. But they also show a negative correlation between the volume of imports and the *share* of local innovations.

How can we reconcile these two statements? In fact, Figure 16 suggests that there is a "crowding out effect". But Figure 15 shows that this effect is compensated by demand factors: when demand for climate change technologies increases in a country, this boosts both local innovations and imports.

Figure 15: Number of inventions and number of imported inventions (logs) for selected countries (1998-2003)

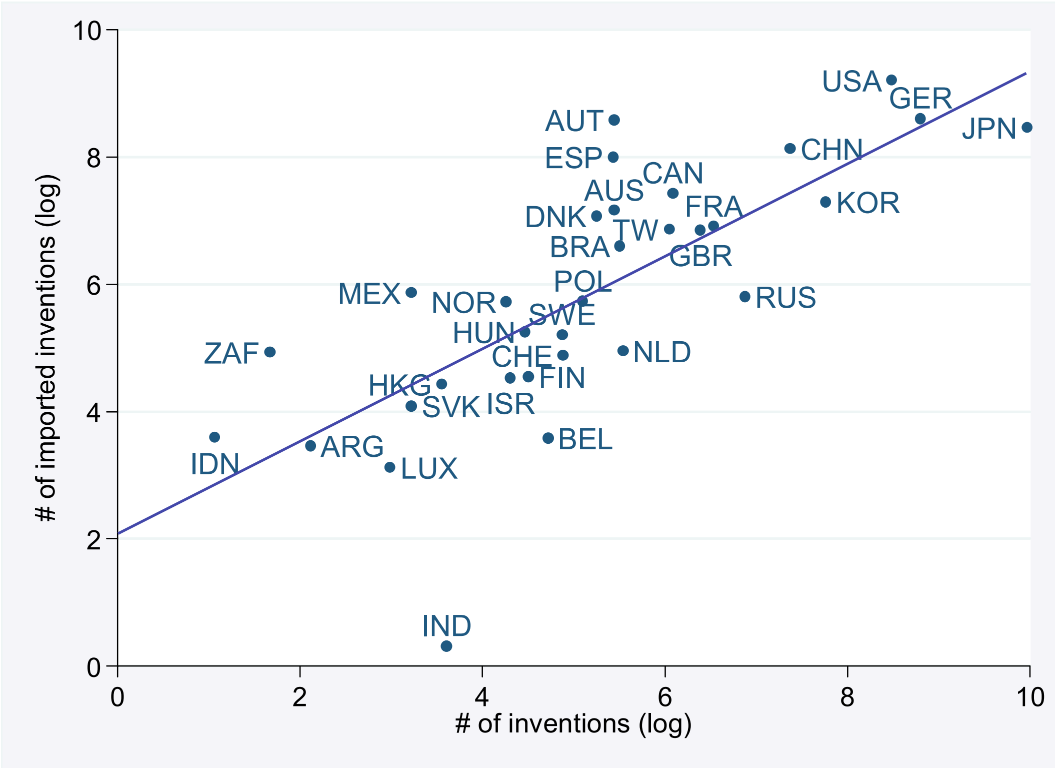
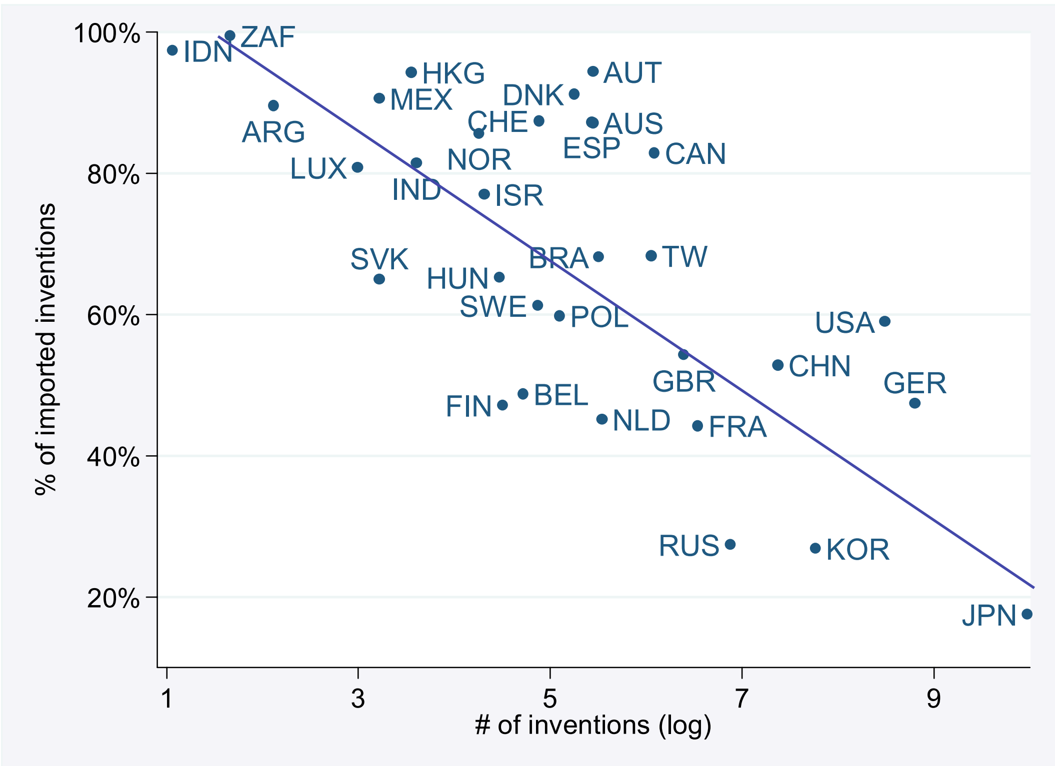


Figure 16: Number of inventions (log) and share of local inventions for selected countries (1998-2003)



6 Econometric analysis of technology diffusion

In the previous sections, we have described the geography and the trends in innovation and technology transfer. But these statistics do not help us to understand the causes of these observations. For instance, why do most technology imports occur in industrialized countries? Is it so because these countries have the necessary technological knowledge and expertise to absorb new technologies? Or because Intellectual Property Rights are sufficiently enforced so that the risk of imitation is limited? In this section we use econometric models to address this type of questions. We focus the analysis on the issue of technology diffusion.

6.1 Research questions

We seek to answer 5 questions:

Question 1: Does accumulated knowledge facilitate the import of technology? Empirical evidence indicates that the accumulation of knowledge in a country increases its capacity to import new technologies (Blackman, 1997). Is it true for climate change technologies? More specifically, what does this technology absorptive capacity consist in? Generic skills? Technology-specific knowledge?

Question 2: Does the import of foreign technologies crowd out local innovation? The local production of innovation is likely to have a direct impact on the flow of technology coming from abroad. This impact may be either positive or negative, depending on whether local and foreign patents are substitutes or complements.

Question 3: Do strict Intellectual Property Rights promote technology transfer? Several papers highlight the fact that effective patent protection is a means to promote the transfer of green technologies towards developing countries (see for example Maskus, 2000 and Barton, 2007). However, strict Intellectual Property Rights (IPR) may have contrasting effects on patent transfers. On the one hand, a higher IPR protection increases the inventor's incentives to patent abroad. On the other hand, reinforcing patent protection is likely to increase the administrative and legal costs associated with patent filing and enforcement, thereby reducing the flows of patents.

Question 4: Do restrictions on international trade hinder technology transfer? Technologies may be embodied in capital equipment goods. In this case patenting can protect the inventor against imitation by reverse engineering. Arguably, restrictions to trade hinder the transfer of these technologies.

Question 5: Do restrictions on Foreign Direct Investments hinder technology transfer? FDI is another well-known channel through which technologies and knowledge cross national borders.

6.2 The model

In order to address the above questions, we propose an econometric model in which the dependent variable which we seek to explain is $P_{i,j,t}$; the number of patents invented in country *i* and filed in country *j* in year *t*. In other terms, the dependent variable is the yearly count of exported patents for every pair of countries. Since we focus on international flows of technology, we consider only patents whose inventor is not a resident of the country ($i \neq j$).

We construct one panel data set for each technology class previously described. However we do not consider climate-friendly cement and CCS. These data sets have too few observations and raised convergence problems. Estimating the model on each technology field allows us to control for field-specific characteristics. Using technology-specific data sets ensures that the significant differences in the propensity to patent across industries do not have any influence on our results. The panels go over 13 years, from 1990 to 2003. We have taken 1990 as the starting date because we lack complete data on former USSR before 1990.

The basic regression model we use is as follows:

$$\begin{aligned}
P_{i,j,t} = {} & \alpha_0 + \alpha_1(INNOVATION_STOCK_{j,t}) + \alpha_2(EDUCATION_{j,t}) \\
& + \alpha_3(LOCAL_INNOVATION_{j,t}) + \alpha_4(IPR_STRICTNESS_{j,t}) \\
& + \alpha_5(IMPORT_TARIFF_{j,t}) + \alpha_6(TRADE_BLOC_{i,j,t}) + \alpha_7(FDI_CONTROL_{j,t}) \\
& + \alpha_8(AVAIL_PATENTS_{i,t}) + \alpha_9(DISTANCE_{i,j}) + \alpha_{10}(COM_LANGUAGE_{i,j}) \\
& + \alpha_{11}(POPULATION_{j,t}) + \alpha_{12}(GDP_GROWTH_{j,t}) + \alpha_{13}(PAT_BREATH_EXP_i) \\
& + \alpha_{14}(PAT_BREATH_REC_j) + \alpha_n(YEAR_{i,j}) + \varepsilon_{i,j,t}
\end{aligned} \tag{1}$$

$\varepsilon_{i,j,t}$ is the error term, which includes unobservable country-pair specific effects, $\mu_{i,j}$ and random-time varying effects, $\nu_{i,j,t}$; that is $\varepsilon_{i,j,t} = \mu_{i,j} + \nu_{i,j,t}$.

We now review the explanatory variables we use to address to the different research questions.

Question 1: Does accumulated knowledge facilitate the import of technology?

We seek to understand whether transferring a technology requires generic skills and/or technology-specific knowledge. This leads us to use two different variables to describe local technological knowledge. *INNOVATION_STOCK* is the discounted stock of previously filed patents in the technology. This is an indicator of the local absorptive capabilities which are specific to each technology. Note that we only take into account patents filed by local inventors. By contrast, *EDUCATION* is the tertiary gross enrollment ratio, i.e. the percentage of the population of official school age for tertiary education actually enrolled in this level. This variable captures the generic technological knowledge available locally

Following Peri (2005), the patent stock is calculated using the perpetual inventory method. We initialize patent stocks for the year 1978 and use the recursive formula:

$$S_t = (1-\delta)S_{t-1} + P_t$$

where P_t is the number of patents in year *t*. The value chosen for δ, the depreciation of R&D capital, is 10%, a value commonly used in most of the literature (see Keller, 2002). In order to take inventions patented prior to 1978 into account, we set the initial value of knowledge stock at:

$$S_{1978} = \frac{P_{ini}}{(\delta + g)}$$

where *g* is the average worldwide growth rate of patenting activity in the technology for the period 1978-1983 and P_{ini} is the average annual number of patents filed between 1978 and 1980. Calculating a three-year average limits the influence of annual fluctuations and avoids problems arising when $P_{1978} = 0$. Note that since we perform regressions on the 1990-2003 period, the influence of the calculated initial stocks is greatly diminished.

In accordance with similar studies, we use the log of the stocks and lag the variables by 1 year to predict transfers in year *t* given the stocks in year *t*-1.

Question 2: Does local innovation crowd out the import of foreign technologies?

The number of patents filed by local inventors is described by the variable *LOCAL_INNOVATION*. Unfortunately, this variable is probably endogenous as our models do not include any variables reflecting the demand for innovation—e.g., energy prices, policy factors—for these data are not available at the disaggregated level. This may create endogeneity because both the dependent variable and *LOCAL_INNOVATION* are influenced by these demand factors. The standard solution to this problem—instrumental variable estimation—cannot be implemented as an appropriate instrument is lacking. Dismissing the variable would not be satisfactory as well as it would create an omitted variable bias.

We treat the problem by lagging the variable by 1 year. This solution is based on the fact that after taking individual effects into account, any time varying correlation between the error term and the endogenous variables is only contemporaneous. However the solution is arguably partial and results should be interpreted with caution.

Question 3: Do strict Intellectual Property Rights promote technology transfer?

To proxy the strictness of IPR in the recipient country, we use the variable *IPR_STRICTNESS* which is the index of patent rights built by Park and Lippoldt (2008).

Question 4: Do restrictions on international trade hinder technology transfer?

To answer this question, we use two variables to proxy trade restrictions. *IMPORT_TARIFF* is the unweighted mean of tariff rates based on data from the World Economic Forum and the International

Monetary Fund. *TRADE_BLOC* is a dummy variable indicating whether the countries are part of the same trade bloc.

Question 5: Do restrictions on Foreign Direct Investments hinder technology transfer?

We include in the regressions the variable *FDI_CONTROL* which is an index of international capital market controls based on data from the World Economic Forum and the International Monetary Fund[8].

Control variables

In addition, we include a set of control variables. *AVAIL_PATENTS* represents the number of patents filed by originating country's inventors in their own country in year t-1. Inventors usually patent their invention in their own country before seeking legal protection in other patent offices. Subsequent filings must be made within 18 months after the first date of filing. Thus, this variable controls for opportunities for patent filings in foreign countries.

Patent flows between two countries may depend on geographic characteristics. Empirical evidence shows that knowledge flows are affected by distance (Peri, 2005)—though less than trade flows. Moreover, one can reasonably assume that filing a patent in a country where the same language is spoken reduces transaction costs. Indeed the applicant saves translation costs and national legal systems are likely to be closer. $DISTANCEi_j$ is simply the log of the geographic distance between country *i* and country *j*[9]. *COM_LANGUAGE* is a dummy variable which equals 1 if both countries share a common official language and 0 otherwise.

As larger countries are likely to have more technologies already available locally, we include *POPULATION* which is the log of recipient country's population as a control variable. Note that we do not use the per capita GDP due to a high correlation with knowledge stocks. We use *GDP_GROWTH* as a proxy for the demand for technology[10]. Finally, *YEAR* is a vector of year dummies. This captures any fixed effects in patent flows common to a year. The number of patents has increased a lot recently and a growth in patent flows may just reflect this increase in patenting activity.

We finally include *PAT_BREADTH_EXP* and *PAT_BREADTH_REC*, denoting respectively the calculated patent breadth weights in the exporting and in the recipient country. Since the regressions are run directly on patent counts, this makes it possible to control for cross-country differences in patent breadth, without altering the raw data set.

6.3 Econometric issues

A notable feature of patent data is that most patents are only filed in one country (usually, the inventor's country), implying that the patent flow between two countries frequently equals zero. When dealing with count data with many zeros, the Poisson distribution is very restrictive as it imposes the mean to be equal to the variance. The standard method to test and correct for over-dispersion is the use of a negative binomial regression model, which is a Poisson maximum likelihood regression with over-dispersion. We use this solution.

A problem arising when analyzing data on a time series of cross-sections, or panel data, is the possibility of unobserved time-invariant effects called unobserved heterogeneity. This issue is of particular importance in this study for two main reasons. First, the flows of patents between two countries are likely to be affected by their prior bilateral history. Second, it is well known among experts in intellectual property rights that the number of patents granted for a given innovation varies significantly across countries as argued previously.

Two approaches used to address problems of unobserved heterogeneity statistically are fixed- and random-effects models. Fixed-effects models treat the unobserved individual effect as a constant over time and compute it for each group (country pair). The method estimates a constant term for each distinct group and includes a dummy variable for each. Random-effects models treat the heterogeneity that varies across groups as randomly drawn from a normal probability distribution.

We have opted for a random-effects negative binomial model for the following reasons. First, parameters of time-invariant variables cannot be estimated with the fixed-effects model. This would have meant excluding several variables that are likely to have a significant impact such as distance or common language. Second, using a fixed-effects model would cause all groups with 0 patent transferred during the 1990-2003 period to be dropped from the regression. This would induce a problem of selection bias as we would exclude many potential technology suppliers from the sample. Third,,the breadth of patents—a major component of the individual effects—is normally distributed among patent offices, as shown in Annex 11. Last, in their study of patent applications, Hausman et al. (1984) show that the random effect negative binomial model provides more efficient estimators than the fixed effect model.

6.4 Results

Results are presented in Tables 7 to 9. We now review the five questions.

Question 1: Does accumulated knowledge facilitate the import of technology

The local stock of technology-specific knowledge *INNOVATION_STOCK* has a clear positive impact on the flows of patents. The coefficient is statistically significant at the 0.1% level in ten fields out of 11. This shows that patent flows tend to increase if the recipient country is actively involved in R&D in the same technology field.

The recipient country's level of education is statistically significant and has a positive impact only in six regressions. This suggests that generic absorptive capabilities are less important than technology-specific knowledge.

Question 2: Does local innovation crowd out the import of foreign technologies?

The local production of innovation increases the incoming flows of patents in 5 regressions. Local innovation does not seem to crowd out imports. The reason is probably that local innovation and imports are both correlated to demand variables that are not included in the equation.

Question 3: Do strict Intellectual Property Rights promote technology transfer?

In seven regressions, changes in IPR strictness have no effect on patent flows. In four sectors—namely buildings insulation, wind power, fuel injection and energy-efficient lighting—,stricter patent protection increases patent flows. This suggests that, in some sectors, IPR protection is not a key driver of the diffusion of climate mitigation technologies.

Question 4: Do restrictions on international trade hinder technology transfer?

Restrictions to trade seem to be more problematic than IPR strictness: higher tariff rates have a statistically significant negative impact on patent flows in ten regressions. This result is confirmed by the fact that being part of the same trade bloc significantly increases patent flows in eight regressions. This suggests that transferred technologies are frequently embodied in equipment goods.

Question 5: Do restrictions on Foreign Direct Investments hinder technology transfer?

Finally strict international capital control does not have any statistically significant effect on patent flows in most regressions. However the coefficient is counter-intuitively positive in cement and methane destruction. Several interpretations are possible: first, strict FDI regulations may consist in requiring the transfer of technology in foreign investments. Second, restrictions on FDI may shift technology transfer to other channels, such as licensing to local users, that require more patenting than FDI. To sum up, one should be cautious when interpreting these results.

Table 7: Regression results (cement, waste, lighting & buildings)

Variable	buildings	Cement	waste	lighting
INNOVATION_STOCK	–0.01179	0.11715***	0.20532***	0.14201***
	(0.01012)	(0.02503)	(0.01435)	(0.01522)
EDUCATION	0.00556**	0.0088**	–0.00393	0.00936***
	(0.00208)	(0.00324)	(0.00212)	(0.00202)
LOCAL_INNOVATION	0.00251***	0.0041	0.00036***	0.00023***
	(0.00039)	(0.00298)	(0.00011)	(0.000042)
IPR_STRICTNESS	0.54446***	0.1853	0.06444	0.21556**
	(0.0735)	(0.11206)	(0.07819)	(0.07857)
IMPORT_TARIFF	–0.05106***	–0.05453***	–0.04841***	–0.03261***
	(0.00796)	(0.01092)	(0.00793)	(0.00738)
TRADE_BLOC	0.07556	0.20536	0.61163***	0.64619***
	(0.07836)	(0.14571)	(0.11652)	(0.1223)
FDI_CONTROL	0.01782	0.07143*	0.00848	0.03672
	(0.02038)	(0.03115)	(0.02198)	(0.02074)
AVAIL_PATENTS	0.00489***	0.01962***	0.00135***	0.0005***
	(0.00034)	(0.00219)	(0.000083)	(0.000033)
COM_LANGUAGE	0.51439**	0.66607**	0.57284***	–0.07764
	(0.16417)	(0.21737)	(0.16816)	(0.14412)
DISTANCE	–0.56533***	–0.37847***	–0.29417***	–0.21726***
	(0.05502)	(0.07241)	(0.0641)	(0.05491)
GDP_GROWTH	0.00324	0.02045	–0.00272	–0.0008
	(0.00847)	(0.01383)	(0.0087)	(0.00785)
POPULATION	0.4382***	0.3523	0.23414***	0.14796***
	(0.03744)	(0.05989)	(0.03706)	(0.03751)
PAT_BREADTH_EXP	2.2285***	2.8578***	0.77051	1.8045***
	(0.4191)	(0.63689)	(0.39344)	(0.33951)
PAT_BREADTH_REC	–0.25354	–1.5941**	–0.85321	1.1262**
	(0.45868)	(0.57843)	(0.47201)	(0.40404)
CONSTANT	–2.0504**	–1.2701	0.04718	–0.81651
	(0.67015)	(0.97405)	(0.72794)	(0.63277)
# of observations	54340	54340	54340	54340

Notes: Year dummies included. Standard error in parentheses; * denotes significance at 5% level, ** denotes significance at 1% level, and *** denotes significance at 0.1% level.

Table 8: Regression results (hydro, fuel injection & methane)

Variable	methane	Fuel injection	hydro
INNOVATION_STOCK	0.25012***	0.11319***	0.23512***
	(0.02968)	(0.01245)	(0.03081)
EDUCATION	0.00655*	0.00144	0.0047
	(0.00279)	(0.00201)	(0.00371)
LOCAL_INNOVATION	0.00212	0.00029***	–0.000067
	(0.00155)	(0.000069)	(0.00375)
IPR_STRICTNESS	0.13171	0.29349***	0.06623
	(0.09324)	(0.07315)	(0.12879)
IMPORT_TARIFF	–0.05353***	–0.03064***	–0.04293***
	(0.00915)	(0.00676)	(0.01268)
TRADE_BLOC	0.44602***	0.51837***	0.85969***
	(0.11567)	(0.09078)	(0.17329)
FDI_CONTROL	0.06434*	–0.03056	–0.02927
	(0.0253)	(0.0182)	(0.03607)
AVAIL_PATENTS	0.00741***	0.00079***	0.02044***
	(0.00096)	(0.000054)	(0.00269)
COM_LANGUAGE	0.53731**	–0.00728	0.71311***
	(0.18761)	(0.1471)	(0.20524)
DISTANCE	–0.41617***	–0.23776***	–0.10626
	(0.06477)	(0.0526)	(0.07435)
GDP_GROWTH	0.01562	–0.01755*	–0.01469
	(0.0113)	(0.00737)	(0.01654)
POPULATION	0.37058***	0.27935***	0.3796***
	(0.04738)	(0.03421)	(0.05945)
PAT_BREADTH_EXP	1.6425***	0.68922*	1.7948***
	(0.45423)	(0.32377)	(0.54089)
PAT_BREADTH_REC	–0.8384	0.7008	0.02136
	(0.52976)	(0.45272)	(0.68244)
CONSTANT	–1.6018*	–1.9378***	–2.6673**
	(0.7837)	(0.5841)	(0.98861)
# of observations	54340	54340	54340

Notes: Year dummies included. Standard error in parentheses; * denotes significance at 5% level, ** denotes significance at 1% level, and *** denotes significance at 0.1% level.

Table 9: Regression results (wind power, biomass, ocean & solar)

Variable	Wind power	Ocean	Solar	Biomass
INNOVATION_STOCK	0.10903***	0.27489***	0.42191***	0.1536***
	(0.01261)	(0.03195)	(0.02876)	(0.02019)
EDUCATION	0.00516*	0.01012**	–0.00059	0.00433
	(0.00244)	(0.00327)	(0.00219)	(0.00233)
LOCAL_INNOVATION	0.00067*	0.00409	0.00048	0.00063
	(0.0003)	(0.00392)	(0.00026)	(0.00097)
IPR_STRICTNESS	0.26009**	–0.22589	0.08496	0.06929
	(0.09154)	(0.11999)	(0.0742)	(0.08331)
IMPORT_TARIFF	–0.06215***	–0.05073***	–0.00808	–0.03537***
	(0.00967)	(0.01195)	(0.00645)	(0.00794)
TRADE_BLOC	0.83486***	1.6605***	0.28402**	0.17861
	(0.13347)	(0.17908)	(0.0993)	(0.11044)
FDI_CONTROL	0.03656	0.00091	–0.00848	–0.04474
	(0.02556)	(0.03294)	(0.01928)	(0.02476)
AVAIL_PATENTS	0.00258***	0.02906***	0.00217***	0.00677***
	(0.00022)	(0.00267)	(0.00017)	(0.00069)
COM_LANGUAGE	0.11519	0.89846***	0.72085***	0.7614***
	(0.16218)	(0.17923)	(0.16402)	(0.18597)
DISTANCE	–0.21173***	0.09231	–0.22899***	–0.40776***
	(0.05928)	(0.07362)	(0.05714)	(0.06946)
GDP_GROWTH	–0.00455	0.01527	0.00612	–0.00393
	(0.01049)	(0.01519)	(0.00841)	(0.00991)
POPULATION	0.36501***	0.29207***	0.14384***	0.29982***
	(0.03744)	(0.05143)	(0.04056)	(0.04783)
PAT_BREADTH_EXP	0.22428	–0.0636	1.7523***	1.5114**
	(0.37733)	(0.4151)	(0.39653)	(0.47549)
PAT_BREADTH_REC	–0.84444	–1.413***	–0.01482	–0.60939
	(0.4519)	(0.51055)	(0.47997)	(0.51778)
CONSTANT	–2.7391***	–2.9003**	–0.47871	0.0971
	(0.70993)	(1.048)	(0.679)	(0.83243)
# of observations	54340	54340	54340	54340

Notes: Year dummies included. Standard error in parentheses; * denotes significance at 5% level, ** denotes significance at 1% level, and *** denotes significance at 0.1% level.

7 Conclusion

In this paper we use the PATSTAT database to identify and analyze patented inventions in 13 climate-related technology classes between 1978 and 2003. This allows us to draw major conclusions concerning the dynamics and distribution of innovation, and the international transfer of technology.

A first set of results concern the impact of the Kyoto Protocol. Statistics suggest the protocol has induced more innovation in the recent period. While innovation in climate change technologies and innovation in all technologies were growing at the same pace until the mid-nineties, the former is now developing much faster. Between 1998 and 2003, innovation in climate mitigation technologies has been growing at the average annual rate of 9%. This increase has only taken place in Annex 1 countries which have ratified the Kyoto Protocol—as opposed to Australia and the USA.

In contrast, there is no visible effect of the Kyoto protocol on technology transfer: international technology flows have actually been increasing in the recent period, but the growth rate is the same as the average.

Our study also yields information on who are the major inventor countries. We show that innovation in climate change technologies is highly concentrated in three countries, namely Japan, Germany and the USA, which accounts for two thirds of total climate innovations in our thirteen technologies. The performance of Japan is particularly impressive as it ranks first in twelve technology fields out of 13. In average it accounts for 42 percent of worldwide innovation.

Surprisingly, the innovation performance of emerging economies is far from being negligible as China, South Korea and Russia are respectively the fourth, fifth and sixth largest innovators. They globally represent about 15% of global inventions.

Do these new technologies cross national borders? The export rate—measured by the share of inventions that are patented in at least two countries—is around 25%. This sounds small, but it is only a few percents below the rate for all technologies. International transfers mostly occur between developed countries (75% of exported inventions). Exports from developed countries to emerging economies are still limited (18%) but are growing rapidly. This suggests a huge potential for the development of North-South transfers. Although China, Russia and South Korea are major innovators, flows between emerging economies are almost non-existent. Accordingly, there also exists a huge potential for South-South exchanges—particularly given that these countries may have developed technologies that are better tailored to the needs of developing countries.

Finally we have run econometric regressions to identify the factors which promote or hinder the international diffusion of technologies. They show that absorptive capacities of recipient countries are determinant factors. This is particularly true for technology-specific knowledge whereas the general level of education exerts less influence. We have also sought to identify the impacts of different policy barriers. The results stress that restrictions to international trade—e.g., high import tariff rates—

particularly hinder the import of technologies. In contrast, lax intellectual property regimes negatively influence the quantity of transfers, but only for a limited number of technologies. Barriers to Foreign Direct Investments also seem to have a limited influence. However these econometric results need to be confirmed by the use of more sophisticated models and should be considered with caution in the meantime.

In conclusion, it is useful to recall the limits of our analysis. Its main shortcoming is probably that patents are imperfect proxies of innovation and technology transfer, and we have explained why in the paper. But they are currently the only data available to investigate climate change technologies world wide.

Notes

(1) Two types of patent are excluded from our search: utility models and design applications. Utility models are of shorter duration than regular patents and do not require the same inventive step. Registered designs protect only the appearance of products, for example the look of a computer monitor.

(2) Some previous studies have related patent classes to industrial sectors using concordances (e.g. Jaffe and Palmer 1997). The weaknesses of such an approach are twofold. First, if the industry of origin of a patent differs from the industry of use, then it is not clear to which industrial sector a patent should be attributed in the analysis. This is important when studying specifically "environmental" technology because in this case the demand (users of technology) and supply (inventors of technology) of environmental innovation may involve different entities. Often, "environmental" innovations originate in industries which are not specifically environmental in their focus. On the other hand, some "environmental" industries invent technologies which are widely applicable in non-environmental sectors (e.g. processes for separation of waste; separation of vapors and gases). More fundamentally, the use of sectoral classifications (and commodity classifications) will result in a bias toward the inclusion of patent applications from sectors that produce environmental goods and services. By contrast, the application-based nature of the patent classification systems allows for a richer characterization of relevant technologies. (See OECD 2008 for a full discussion of the relative merits of the approach adopted for this report.)

(3) The International Patent Classification can be searched for keywords at http://www.wipo.int/tacsy/

(4) Available at http://ep.espacenet.com/

(5) Patents with multiple inventors are counted fractionally. For example, if two inventor countries are involved in an invention, then each country is counted as one half.

(6) Nuclear not included. Source: Lazarus & Kartha (2007)

(7) Note that Least Developed Countries are not present in our dataset, for two related reasons: their patenting activity is extremely limited, and available statistics are not reliable.

(8) The average tariff rate and the index of international capital market controls are from the Economic Freedom of the World 2008 Annual Report. Missing years were filled by interpolation.

(9) Distances between countries were taken from the online CEPII datasets available at http://www.cepii.fr/anglaisgraph/bdd/distances.htm

(10) GDP growth and population were obtained from the World Bank's World Development Indicators 2008

References

Barton, J., 2007. Intellectual Property and Access to Clean Energy Technologies in Developing Countries. An Analysis of Solar Photovoltaic, Biofuel and Wind Technologies. ICTSD Programme on Trade and Environment, Issue Paper No. 2.

Blackman A., 1999. The Economics of technology diffusion: implications for climate policy in developing countries, Discussion Paper 99-42, Resources For the Future, Washington DC.

Chintagunta, P. K., D. C. Jain and N. J. Vilcassim (1991). 'Investigating heterogeneity in brand preference in logit models for panel data', *Journal of Marketing Research*, **27**, pp. 417–428.

Co, C., 2002. Evolution of the geography of innovation: evidence from patent data. Growthand Change Vol. 33 No. 4 pp. 393-423.

Cohen, W.M., Nelson, R.R., Walsh, J.P., 2000. Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). NBER Working Paper no. 7552.

Dernis, H., Guellec, D., 2001. Using Patent Counts for Cross-Country Comparisons of Technology Output, STI Review 27 (http://www.oecd.org/LongAbstract/0,3425,en_2649_33703_21682516_1_1_1_1,00.html).

Eaton, J., Kortum, S., 1996. Trade in ideas Patenting and productivity in the OECD. Journal of International Economics, vol. 40(3-4), pages 251-278, May

Eaton, J., Kortum, S. 1999. International Technology Diffusion: Theory and Measurement. International Economic Review, Department of Economics, University of Pennsylvania and Osaka University Institute of Social and Economic Research Association, vol. 40(3), pages 537-70, August.

Enkvist, P.-A., Nauclér, T., Rosander, J., 2007. A cost curve for greenhouse gas reduction. The McKinsey Quarterly, McKinsey & Company, 2007.

Frietsch, R., Schmoch, U. 2006. Technological structures and performance as reflected by patent indicators. in Schmoch, U.; Rammer, C.; Legler, H. (eds.) *National Systems of Innovation in comparison. Structure and performance indicators for knowledge societies*. (Dordrecht: Springer)

Griliches, Z., 1990. Patent Statistics as Economic Indicators: A Survey. Journal of Economic Literature, Vol. 28, No. 4, pp. 1661-1707.

Gulati, R., 1999. Network location and learning: The influence of network resources and firm capabilities on alliance formation. Strategic Management Journal 20 (5), 397–420.

Heckman, J. (1981). 'Statistical models for discrete panel data'. In D. McFadden and C. Manski (eds.), *The Econometrics of Panel Data*. MIT Press, Cambridge, MA, pp. 114–178.

Helfgott, S., 1993. Patent filing costs around the world. Journal of the Patent and Trademark Office Society, July, pp. 567-580.

Hoekman, B. M., Maskus, K. E., Saggi, K., 2005. Transfer of technology to developing countries: Unilateral and multilateral policy options, World Development, vol. 33(10), pages 1587-1602.

Jaffe, A.B., Palmer, K., 1997. Environmental regulation and innovation: a panel data study. Review of Economics and Statistics 79, 610– 619.

Keller; W., 2002. Geographic localization of international technology diffusion, American Economic Review92, 120-142.

Lanjouw, J.O., Mody, A., 1996. Innovation and the International Diffusion of Environmentally Responsive Technology. Research Policy, Vol. 25, pp. 549-571.

Lanjouw, J., Pakes, A. and Putnam, J., 1998. How to Count Patents and Value Intellectual Property: The Uses of Patent Renewal and Application Data. *The Journal of Industrial Economics*, 46 (4), pp. 405-32.

Lazarus, M., Kartha, S., 2007. Lier le développement technologique et les engagements en matière d'émissions : recheche de mesures de résultats et d'efforts. Rapport à l'ADEME. Stockholm Environment Institute.

Maskus, K. E., 2000. Intellectual Property Rights in the Global Economy. Institute for International Economics, Washington D.C.

McKinsey & Vattenfall, 2007. A global mapping of Greenhouse Gas abatement opportunities up to 2030. Available at http://www.vattenfall.com/www/ccc/ccc/577730downl/index.jsp

OECD, 2008. Main Science and Technology Indicators (Paris: OECD).

Park, W. G., Lippoldt, D. C., 2008. Technology Transfer and the Economic Implications of the Strengthening of Intellectual Property Rights in Developing Countries, OECD Trade Policy Working Papers 62, OECD Trade Directorate.

Peri, G., 2005. Determinants of knowledge flows and their effect on innovation. Review of Economics and Statistics 87 (2), 308– 322.

Roland Berger Market Research, 2005. Study on the cost of patenting. Available at: http://www.european-patent-office.org/epo/new/cost_analysis_2005_study_en.pdf

Smith, P. J., 2001. How do foreign patent rights affect U.S. exports, affiliate sales, and licenses? Journal of International Economics, 55, 411-439.

Annex 1. Definition of IPC codes

Description	Class
Buildings	
Insulation or other protection; Elements or use of specified material for that purpose.	E04B 1/62
Heat, sound or noise insulation, absorption, or reflection; Other building methods affording favorable thermal or acoustical conditions, e.g. accumulating of heat within walls	E04B 1/74–78
Insulating elements for both heat and sound	E04B 1/88
Units comprising two or more parallel glass or like panes in spaced relationship, the panes being permanently secured together	E06B 3/66–67
Wing frames not characterized by the manner of movement, specially adapted for double glazing	E06B3/24
Use of energy recovery systems in air conditioning, ventilation or screening.	F24F 12/00
Biomass	
Solid fuels based on materials of non-mineral origin—animal or plant	C10L 5/42-44
Engines operating on gaseous fuels from solid fuel—e.g. wood	F02B 43/08
Liquid carbonaceous fuels - organic compounds	C10L 1/14
Anion exchange - use of materials, cellulose or wood	B01J 41/16
Carbon capture & storage	
Chemical or biological purification of waste gases—carbon oxides	B01D 53/62
Cement	
Natural pozzuolana cements	C04B 7/12–13
Cements containing slag	C04B 7/14–21
Iron ore cements	C04B 7/22
Cements from oil shales, residues or waste other than slag	C04B 7/24-30
Calcium sulfate cements	C04B 11/00
Fuel injection	
Arrangements of fuel-injection apparatus with respect to engines; Pump drives adapted top such arrangements	F02M 39/00
Fuel-injection apparatus with two or more injectors fed from a common pressure-source sequentially by means of a distributor	F02M 41/00
Fuel-injection apparatus operating simultaneously on two or more fuels or on a liquid fuel and another liquid, e.g. the other liquid being an anti-knock additive	F02M 43/00
Fuel-injection apparatus characterized by a cyclic delivery of specific time/pressure or time/quantity relationship	F02M 45/00
Fuel-injection apparatus operated cyclically with fuel-injection valves actuated by fluid pressure	F02M 47/00
Fuel-injection apparatus in which injection pumps are driven, or injectors are actuated, by the pressure in engine working cylinders, or by impact of engine working piston	F02M 49/00
Fuel injection apparatus characterized by being operated electrically.	F02M 51/00
Fuel-injection apparatus characterized by heating, cooling, or thermally-insulating means	F02M 53/00
Fuel-injection apparatus characterized by their fuel conduits or their venting means	F02M 55/00
Fuel injectors combined or associated with other devices	F02M 57/00
Pumps specially adapted for fuel-injection and not provided for in groups F02M 39/00 to F02M 57/00	F02M 59/00
Fuel injection not provided for in groups F02M 39/00 to F02M 57/00	F02M 61/00

Other fuel-injection apparatus, parts, or accessories having pertinent characteristics not provided for	F02M 63/00
Testing fuel-injection apparatus, e.g. testing injection timing	F02M 65/00
Low-pressure fuel-injection apparatus	F02M 69/00
Combinations of carburetors and low-pressure fuel-injection apparatus	F02M 71/00
Geothermal	
Other production or use of heat, not derived from combustion—using natural or geothermal heat	F24J 3/00-08
Devices for producing mechanical power from geothermal energy	F03G 4/00-06
Hydro power	
Machines or engines of reaction type (i.e. hydraulic turbines)	F03B 3/00
Water wheels	F03B 7/00
Adaptations of machines or engines for liquids for special use; Power stations or aggregates; Stations or aggregates of water-storage type; Machine or engine aggregates in dams or the like; Submerged units incorporating electric generators	F03B 13/06-10
Controlling machines or engines for liquids	F03B15/00
Lighting	
Gas- or vapor-discharge lamps (Compact Fluorescent Lamp)	H01J 61/00
Electroluminescent light sources (LED)	H05B 33/00
Methane capture	
Anaerobic treatment of sludge; Production of methane by such processes	C02F 11/04
Biological treatment of water, waste water, or sewage: Anaerobic digestion processes	C02F 3/28
Apparatus with means for collecting fermentation gases, e.g. methane	C12M 1/107
Ocean power	
Tide or wave power plants	E02B 9/08
Adaptations of machines or engines for special use—characterized by using wave or tide energy	F03B 13/12-26
Mechanical-power-producing mechanisms—using pressure differences or thermal differences occurring in nature; ocean thermal energy conversion	F03G 7/04-05
Water wheels	F03B 7/00
Solar power	
Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation—adapted as conversion devices, including a panel or array of photoelectric cells, e.g. solar cells	H01L 31/042-058
Generators in which light radiation is directly converted into electrical energy	H02N 6/00
Aspects of roofing for energy collecting devices—e.g. including solar panels	E04D 13/18
Use of solar heat, e.g. solar heat collectors; Receivers working at high temperature, e.g. solar power plants; having lenses or reflectors as concentrating elements	F24J 2/06-18
Devices for producing mechanical power from solar energy	F03G 6/00-06
Use of solar heat; Solar heat collectors with support for article heated, e.g. stoves, ranges, crucibles, furnaces or ovens using solar heat	F24J 2/02
Use of solar heat; solar heat collectors	F24J 2/20-54
Drying solid materials or objects by processes involving the application of heat by radiation—e.g. from the sun	F26B 3/28
Waste	
Solid fuels based on materials of non-material origin—refuse or waste	C10L 5/46-48
Machine plant or systems using particular sources of energy—waste	F25B 27/02

Hot gas or combustion—Profiting from waste heat of exhaust gases Incineration of waste—recuperation of heat Plants or engines characterized by use of industrial or other waste gases Prod. of combustible gases—combined with waste heat boilers Incinerators or other apparatus consuming waste—field organic waste Manufacture of fuel cells—combined with treatment of residues	F02G 5/00-04 F23G 5/46 F01K 25/14 C10J 3/86 F23G 7/10 H01M 8/06
Wind power	
Wind motors with rotation axis substantially in wind direction Wind motors with rotation axis substantially at right angle to wind direction Other wind motors Controlling wind motors Adaptations of wind motors for special use	F03D 1/00-06 F03D 3/00-06 F03D 5/00-06 F03D 7/00-06 F03D 9/00-02
Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass	F03D 11/00-04

Annex 2. Number of patent applications and of priorities included in each data set

Technology field	# patent applications	# priorities
Biomass	7,667	2,798
Buildings	20,852	13,366
CCS	954	548
Cement	5,612	3,698
Fuel injection	62,687	32,654
Geothermal	4,120	2,782
Hydro	6,604	5,106
Lighting	71,530	43,351
Methane	9,634	6,235
Ocean	6,235	4,430
Solar	35,342	24,620
Waste	26,354	16,729
Wind	16,309	10,689
Total	**273,900**	**167,006**

Annex 3. Main patent offices and patent breadth coefficients

Patent office	Patent breadth coefficient
Japan	0.71
Taiwan	0.74
Australia	0.79
South Korea	0.81
Russia	0.88
India	0.89
China	0.90
Mexico	0.90
Canada	0.93
Denmark	0.93
UK	0.93
USA	0.96
Switzerland	0.98
Austria	0.99
France	0.99
EPO	1
Belgium	1.01
Italy	1.07
Germany	1.12
Luxembourg	1.13

Annex 4. Data issues

USPTO grants

Up until 2000, the data published by the US Patent and Trademark Office (USPTO) included only those patent applications that were eventually granted, whereas all other offices provide data on applications as well. Therefore, the number of applications filed at the USPTO prior to 2001 needs to be extrapolated, based on other available information. Specifically, the number of US singulars and the share of international families including a US member are multiplied by the yearly ratio of applications filed at the USPTO over granted patents (the inverse of the approval rate of applications). These figures are provided online by the USPTO[1]. For example, 65% of applications were granted in 1978. Consequently, the number of singular US applications and the share of international families including a US member were multiplied by 1.52 for the year 1978.

[1] http://www.uspto.gov/go/taf/us_stat.htm

Missing inventor countries

For 35% of the patent applications included in our data set, the inventor's country of residence is not available. Since the filing of a patent in multiple offices raises the probability of this information being available, this problem mainly concerns patents filed in a single patent office. Assuming that the sub-sample of patents with no information on the inventor's country is randomly drawn from the overall sample of patents, we attribute these patents proportionally to inventor countries on the basis of the average proportion for the same technology field in the same patent office. This average is calculated on the basis of the actual distribution of inventor countries for priority applications between 1978 and 2003[2]. For example, the distribution of the main inventor countries for wind power priority applications filed at the US Patent Office is the following:

Inventor country	Share of patents
USA	82.5%
Canada	5.8%
Taiwan	2.9%
Germany	1.6%
UK	1.2%
Japan	1.1%
Denmark	0.9%
Sweden	0.7%
Others	3.3%

This distribution was used to attribute inventor countries to wind power patents filed at the USPTO when this information was missing.

EPO applications

Patent counts in Europe involve specific difficulties because of the existence of the European Patent System. Inventors have two possibilities to file national patents. They can make applications either at the national patent offices, or at the European Patent Office and then obtain national patents through designation afterwards, if their application is approved. As a consequence, European patent families often include EPO and subsequent national patent applications, the latter corresponding to the designations. Recall that a successful examination at the EPO allows the inventor to obtain patents in all countries of the European Patent System without further examination. Hence, the observed

[2] Due to the small size of samples, calculating the *annual* average distribution of inventor countries would introduce a bigger bias than calculating the 1978-2003 average.

designations correspond to all the countries in which the inventor was seeking patent protection, although there may have been some discrepancy in the past. If a patent was filed first at the EPO, and then at the national office of at least one EPO member state, we considered only the subsequent national applications.

We also observe some EPO applications for which there are no national applications in PATSTAT. It is very likely that such applications have in fact been withdrawn or rejected by the EPO. Since we are interested in all countries in which the inventor was seeking patent protection, we need to take into account these observations. We therefore attribute these patents on the basis of the designations of an average granted EPO patent. More precisely, the attributed designations reflect the average distribution of designated countries of all EPO patents that have one or more designations. This average is calculated on the basis of the actual designations of EPO applications for all IPC classes, for every year. For example, in 1978, EPO patents that have subsequent national designations were eventually filed in an average of 3 countries, the distribution of which is the following:

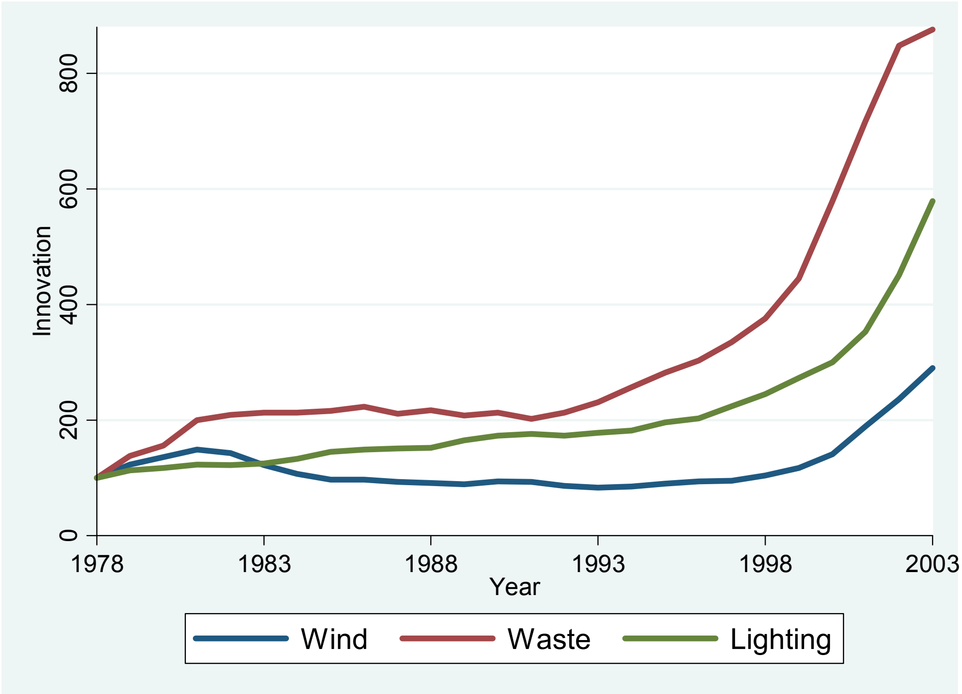
Country	Share of EPO patents filed in that country
Austria	7.8%
Belgium	16.5%
Switzerland	18.0%
Germany	95.0%
France	37.8%
Great-Britain	48.1%
Greece	0.1%
Italy	18.7%
Luxembourg	7.8%
Netherlands	21.7%
Sweden	11.2%

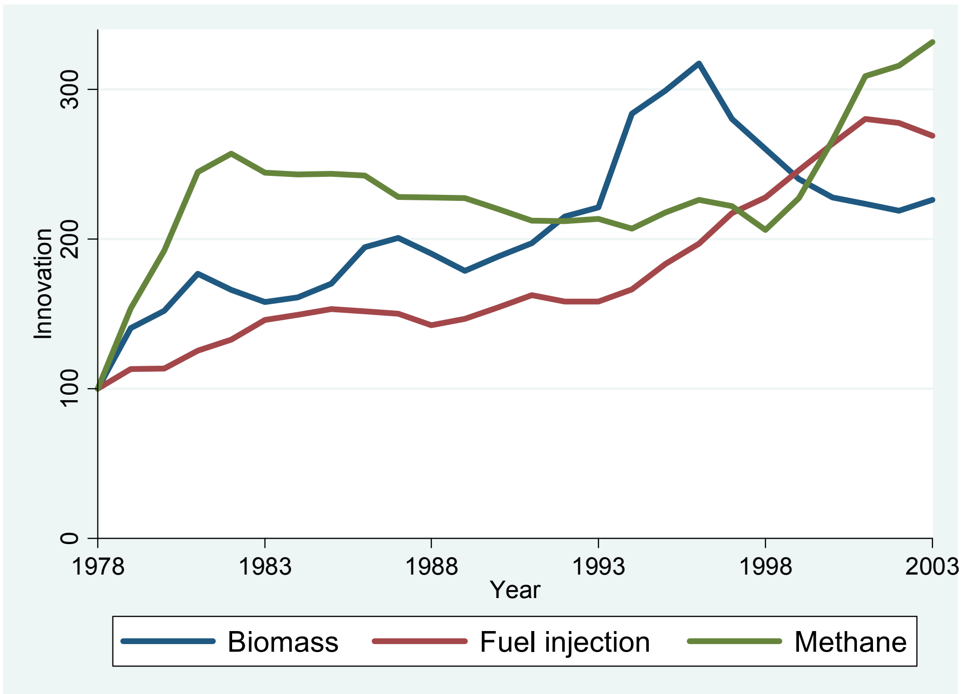
NB: the total is over 100% since EPO patents are usually claimed in several countries, with an average of 3 as noted above.

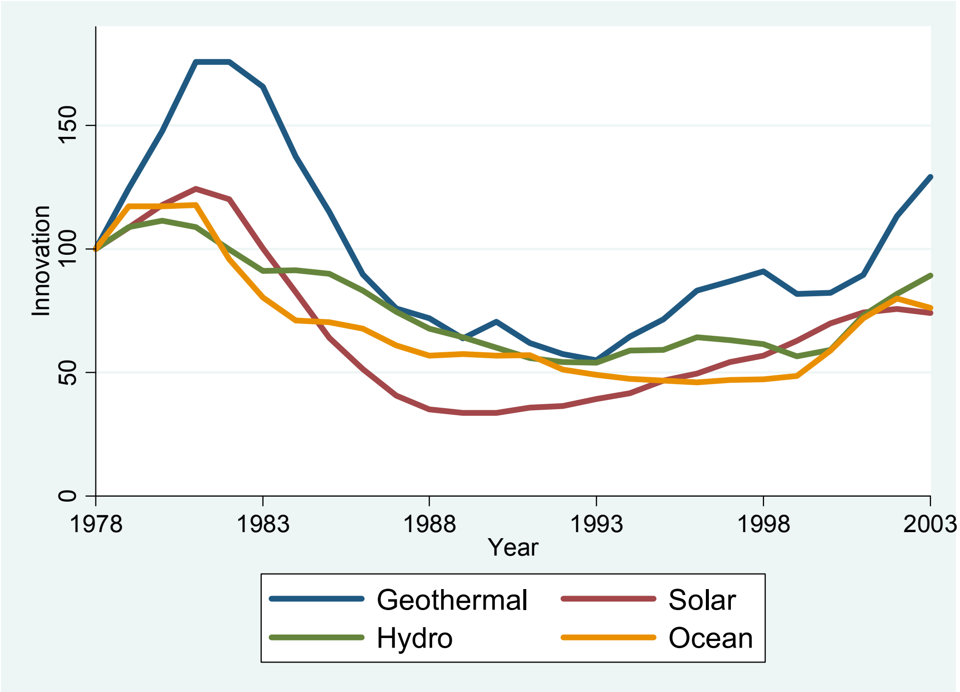
Annex 5. Definition of IPC codes used for benchmarking

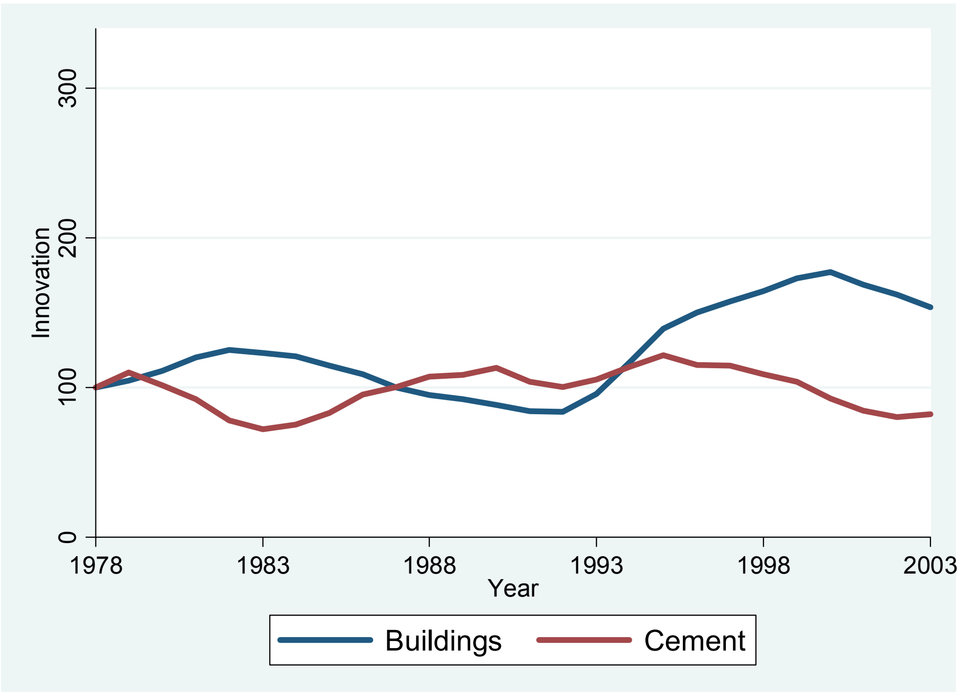
Sector	IPC code	Description
Electricity	H02	Generation, conversion, or distribution of electric power
Vehicles	B62D	Motor vehicles
Buildings	E04	Buildings
	E06	Doors, windows, shutters, or roller blinds
Cement	C04	Cements, concrete, artificial stone, ceramics, refractories
Lighting	F21	Lighting

Annex 6. Pace of innovation in climate change mitigation technologies 1978-2003 (for comparison purposes, the data are normalized to equal 100 in 1978)






Innovation
0
50
100
150
1978
1983
1988
1993
1998
2003
Year
Geothermal
Solar
Hydro
Ocean


Innovation
0
100
200
300
1978
1983
1988
1993
1998
2003
Year
Buildings
Cement

Annex 7: Top 3 inventors for each technology, with % of total inventions (1998 - 2003)

Technology field	First	Second	Third
Biomass	USA (25.8%)	Japan (20.3%)	Germany (16.8%)
Buildings	Japan (47.0%)	Germany (14.4%)	USA (10.8%)
CCS	Japan (45.9%)	USA (27.6%)	Russia (4.8%)
Cement	Japan (38.7%)	China (17.3%)	Russia (7.5%)
Fuel injection	Japan (40.2%)	Germany (32.3%)	USA (13.1%)
Geothermal	Japan (33.1%)	China (12.7%)	Russia (12.2%)
Hydro	Japan (37.1%)	Germany (9.5%)	USA (8.7%)
Lighting	Japan (64.2%)	South Korea (10.3%)	USA (9.9%)
Methane	Japan (52.5%)	Germany (10.7%)	USA (9.7%)
Ocean	Japan (19.9%)	USA (11.4%)	Germany (10.0%)
Solar	Japan (42.0%)	Germany (17.2%)	USA (11.4%)
Waste	Japan (63.1%)	USA (12.3%)	Germany (11.3%)
Wind	Japan (26.3%)	Germany (22.2%)	USA (7.8%)

Annex 8. List of countries by group (developed, emerging & transition)

Developed countries	Transition economies	Emerging countries
Australia	Armenia	Argentina
Austria	Azerbaijan	Brazil
Belgium	Belarus	China
Canada	Bosnia and Herzegovina	Colombia
Denmark	Bulgaria	Egypt
Finland	Croatia	India
France	Czech Republic	Indonesia
Germany	Czechoslovakia	Malaysia
Greece	Estonia	Mexico
Hong Kong	German Democratic Republic	Morocco
Iceland	Hungary	Peru
Ireland	Kazakhstan	Philippines
Israel	Kyrgyzstan	South Korea
Italy	Latvia	South Africa
Japan	Lithuania	Taiwan
Luxembourg	Macedonia	Thailand
Netherlands	Moldova	Turkey
New Zealand	Poland	
Norway	Romania	
Portugal	Russia	
Singapore	Serbia	
Spain	Slovakia	
Sweden	Slovenia	
Switzerland	Soviet Union	
UK	Tajikistan	
USA	Turkmenistan	
	Ukraine	
	Uzbekistan	
	Yugoslavia	

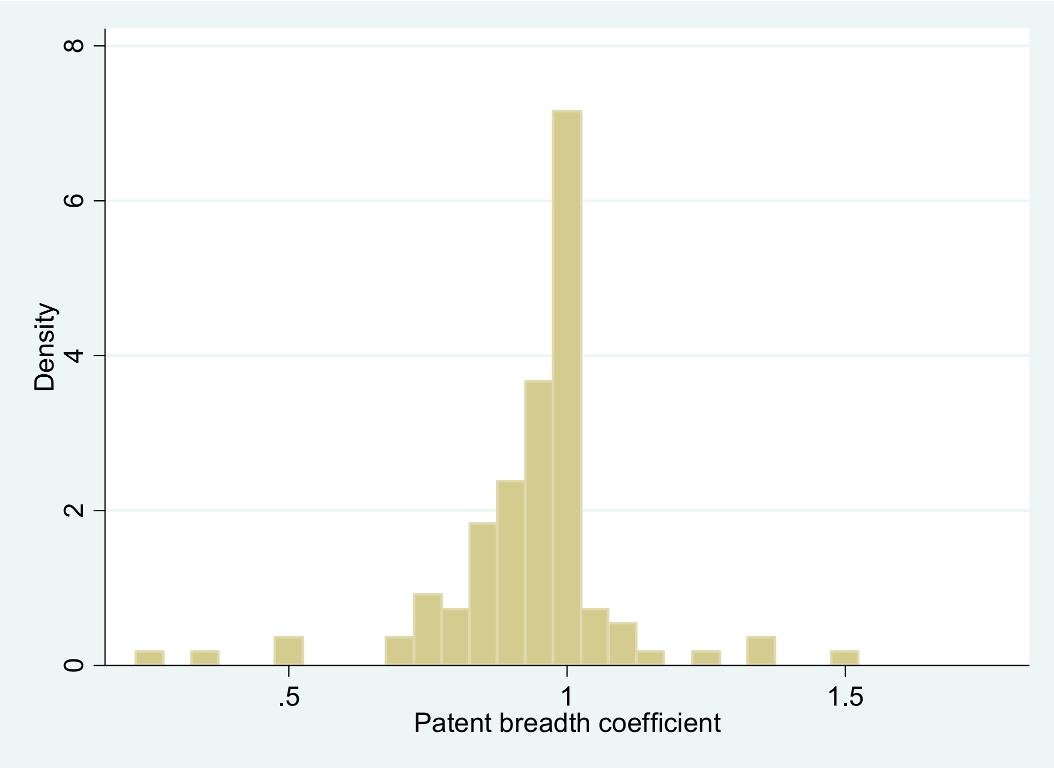
Annex 9. Share of innovation by emerging countries for each technology (average 1978-1983 and average 1998 - 2003)

Technology field	(A) 1978-1983	(B) 1998-2003	(B)/(A)
Biomass	8.7 %	10.9 %	1.3
Buildings	0.9 %	10.7 %	11.9
CCS	0 %	4.8 %	-
Cement	1.4 %	24.7 %	17.6
Fuel injection	1.2 %	3.9 %	3.3
Geothermal	2.0 %	17.4 %	8.7
Hydro	2.8 %	15.5 %	5.5
Lighting	0.7 %	13.6 %	19.4
Methane	1.5 %	12.0 %	8.0
Ocean	2.5 %	21.2 %	8.5
Solar	0.3 %	13.4 %	44.7
Waste	0.1 %	4.3 %	43.0
Wind	3.0 %	9.7 %	3.2

Annex 10. Country codes used for figures 14 to 16

Argentina	ARG	Japan	JPN
Australia	AUS	Mexico	MEX
Austria	AUT	Netherlands	NLD
Belgium	BEL	Poland	POL
Brazil	BRA	Russia	RUS
Canada	CAN	South Africa	ZAF
China	CHN	South Korea	KOR
Denmark	DNK	Spain	ESP
France	FRA	Sweden	SWE
Germany	GER	Switzerland	CHE
Hong Kong	HKG	Taiwan	TW
India	IND	Ukraine	UKR
Indonesia	IDN	United Kingdom	GBR
Israel	ISR	United States	USA
Italy	ITA		

Annex 11. Frequency histogram of patent breadth coefficients



Annex 12. Glossary of Relevant Patent and Related Terms

Adoption: The point at which a technology is selected for use by an individual or an organization.
Applicant: The person or company that applies for the patent and intends to "work" the invention (*i.e.* to manufacture or license the technology). In most countries the inventor(s) does not necessarily have to be the applicant.
Application (or filing) date: The patent application date is the date on which the patent office received the patent application.
Application for a patent: To obtain a patent, an application must be filed with the authorized body (Patent Office) with all the necessary documents and fees. The patent office will conduct an examination to decide whether to grant or reject the application.
Assignee: The person(s) or corporate body to whom all or limited rights under a patent are legally transferred.
Assignment: Transfer of all or limited rights under a patent.
Breadth (or scope): A measure of the extent of the invention covered by a single patent application.
Citations: They comprise a list of references that are believed to be relevant prior art and which may have contributed to the "narrowing" of the original application. Citations may be made by the examiner or the applicant/inventor.
Design applications: Designs can be registered for a wide range of products, including computers, telephones, CD-players, textiles, jewelry and watches. Registered designs protect only the appearance of products, for example the look of a computer monitor. Registration of the design does not protect the way in which the product relating to the design works.

Designated countries: Countries in which patent applicants wish to protect their invention. This concept is specific to European patent applications and international patent applications filed under the Patent Cooperation Treaty (PCT).
Diffusion: The extent to which a technology spreads to general use and application in the economy.
Duplicate: All patents relating to the same invention and sharing the same priority, but filed at patent offices other than the priority office. The count of such patents can be considered as the size of a 'simple' patent family.
ECLA: The European Patent Office's patent classification system. It is based on the IPC Classification System, with greater disaggregation.
Equivalent: A patent that relates to the same invention and shares the same priority application as a patent from a different issuing authority.
Esp@cenet: European Patent Office web site for searching, displaying and downloading patent documents.
European Patent Convention (EPC): The Convention on the Grant of European Patents (European Patent Convention, EPC) was signed in Munich 1973 and entered into force in 1977. As a result of the EPC, the European Patent Office (EPO) was created to grant European patents.
European Patent Office (EPO): The European Patent Office (a regional patents office) was created by the EPC to grant European patents, based on a centralized examination procedure. By filing a single European patent application in one of the three official languages (English, French and German), it is possible to obtain patent rights in all the EPC member and extension countries by designating the countries in the EPO application. The EPO is not an institution of the European Union.
European patent: A European patent can be obtained for all the EPC countries by filing a single application at the EPO in one of the three official languages (English, French or German). European patents granted by the EPO have the same legal rights and are subject to the same conditions as national patents (granted by the national patent office). It is important to note that a granted European patent is a "bundle" of national patents, which must be validated at the national patent office for it to be effective in member countries.
Examiner: An employee of a patent office to whom an application is assigned for handling prosecution.
Grant date: The date when the patent office issues a patent to the applicant. On average it takes three years for a patent to be granted at the USPTO and five years at the EPO.
Grant: A temporary right given by the authorized body for a limited time period (normally 20 years) to prevent unauthorized use of the technology outlined in the patent. A patent application does not automatically give the applicant a temporary right against infringement. A patent has to be granted for it to be effective and enforceable against infringement.
Home Bias: Propensity for the priority country to be the same as the inventor or applicant country.
Infringement: Unauthorized use of a patented invention.
Innovation: The creation or introduction of something new, especially a new product or a new way of producing something.
Intellectual property rights (IPR): IPR allow people to assert ownership rights on the outcomes of their creativity and innovative activity in the same way that they can own physical property. The four main types of intellectual property rights are: patents, trademarks, design and copyrights.
International patent application: Patent applications filed under the Patent Cooperation Treaty (PCT) are commonly referred to as international patent applications. However, an international patent (PCT) application does not result in the issuance of "international patents", *i.e.* at present, there is no global patent system that is responsible for granting international patents. The decision of whether to grant or reject a patent application filed under the PCT rests with the national or regional (*e.g.* EPO) patent offices.
International Patent Classification (IPC): The International Patent Classification, which is commonly referred to as the IPC, is based on an international multilateral treaty administered by WIPO. The IPC is an internationally recognized patent classification system, which provides a common classification for patents according to technology groups. IPC is periodically revised in order to improve the system and to take account of technical development. The current (eighth) edition of the IPC entered into force on 1 January 2006.

Inventor country: Country of the residence of the inventor, which is frequently used to count patents in order to measure inventive performance.

Inventor: Inventor names are recorded for all patents. These appear in the standard last name-initial(s) format.

Japan Patent Office (JPO): The JPO administers the examination and granting of patent rights in Japan. The JPO is an agency of the Ministry of Economy, Trade and Industry (METI).

Lapse: The date when a patent is no longer valid in a country or system due to failure to pay renewal (maintenance) fees. Often the patent can be reinstated within a limited period.

License: The means by which the owner of a patent gives permission to another person to carry out an action which, without such permission, would infringe on the patent. A license can thus allow another person to legitimately manufacture, use or sell an invention protected by a patent. In return, the patent owner will usually receive royalty payments. A license, which can be exclusive or non-exclusive, does not transfer the ownership of the invention to the licensee.

Paris Convention: The Paris Convention for the Protection of Industrial Property was established in 1883 and is generally referred to as the Paris Convention. The Paris Convention established the system of priority rights. Under priority rights, applicants have up to 12 months from first filing their patent application (usually in their own country) in which to make further applications in member countries and claim the original priority date.

Patent Cooperation Treaty (PCT): Signed in 1970, the PCT entered into force in 1978. The PCT provides the possibility to seek patent rights in a large number of countries by filing a single international application (PCT application) with a single patent office (receiving office). The PCT procedure consists of two main phases: (a) an "international phase"; and (b) a PCT "national/regional phase". PCT applications are administered by the World Intellectual Property Organization (WIPO).

Patent family: A patent family is a set of individual patents granted by various countries. The patent family is all the equivalent patent applications corresponding to a single invention, covering different geographical regions. Patent family size is a measure of the geographical breadth for which protection of the invention is sought.

Patent number: A patent number is a unique identifier of a patent. Patent numbers are assigned to each patent document by the patent-issuing authority. The first two letters designate the issuing patent office i.e. EP for EPO patents and US for USPTO patents.

Patent: A patent is an intellectual property right issued by authorized bodies to inventors to make use of, and exploit their inventions for a limited period of time (generally 20 years). The patent holder has the legal authority to exclude others from commercially exploiting the invention (for a limited time period). In return for the ownership rights, the applicant must disclose the invention for which protection is sought. The trade-off between the granting of monopoly rights for a limited period and full disclosure of information is an important aspect of the patenting system.

Patentability: Patentability is the ability of an invention to satisfy the legal requirements for obtaining a patent. The basic conditions of patentability, which an application must meet before a patent is granted, are that the invention must be novel, contain an inventive step (or be non-obvious), be capable of industrial application and not be in certain excluded fields (*e.g.* scientific theories and mathematical methods are not regarded as inventions and cannot be patented at the EPO).

PATSTAT: The EPO's World Patent Statistical Database.

Prior Art: Previously used or published technology that may be referred to in a patent application or examination report. (a) In a broad sense, technology that is relevant to an invention and was publicly available (e.g. described in a publication or offered for sale) at the time an invention was made. (b) In a narrow sense, any such technology which would invalidate a patent or limit its scope. The process of prosecuting a patent or interpreting its claims largely consists of identifying relevant prior art and distinguishing the claimed invention from that prior art.

Priority country: Country where the patent is first filed before being (possibly) extended to other countries.

Priority date: The priority date is the first date of filing of a patent application, anywhere in the world (normally in the applicant's domestic patent office), to protect an invention. The priority date is used to determine the novelty of the invention, which implies that it is an important concept in patent procedures. For statistical purposes, the priority date is the closest date to the date of invention.

Publication lag: In most countries, a patent application is published 18 months after the priority date. For example, all pending EPO and JPO patent applications are published 18 months after the priority date. Prior to a change in rules under the American Inventors Protection Act of 1999, USPTO patent applications were held in confidence until a patent was granted. Patent applications filed at the USPTO on or after 29 November 2000 are required to be published 18 months after the priority date.
Renewal fees: Once a patent is granted, annual renewal fees are payable to patent offices to keep the patent in force. In the USPTO these payments are referred to as maintenance fees.
Term of patent: The maximum number of years that the monopoly rights conferred by the grant of a patent may last.
Trade-Related Aspects of Intellectual Property Rights (TRIPS): Agreement on trade-related aspects of intellectual property rights requires members to comply with certain minimum standards for the protection of IPR. But members may choose to implement laws which provide more extensive protection than is required in the agreement, so long as the additional protection does not contravene the provisions of the agreement. The WTO's TRIPS agreement, negotiated in the 1986-94 Uruguay round, introduced intellectual property rules into the multilateral trading system for the first time.
United States Patent and Trademark Office (USPTO): The USPTO administers the examination and granting of patent rights in the United States. It falls under the jurisdiction of the U.S. Department of Commerce.
Utility model: Also known as "petty patent", these are available in some countries (*e.g.* Japan). This type of patent involves a simpler inventive step than that in a traditional patent and it is valid for a shorter time period.
World Intellectual Property Organization (WIPO) An intergovernmental organization responsible for the negotiation and administration of various multilateral treaties dealing with the legal and administrative aspects of intellectual property. In the patent area, the WIPO is notably in charge of administering the Patent Cooperation Treaty (PCT) and the International Patent Classification system (IPC).

Primary Sources:

OECD, STI/EAS Division *Glossary of Patent Terminology,* 2006
(http://www.oecd.org/dataoecd/5/39/37569498.pdf)

Deardoff's *Glossary of International Economic Terms*
(http://www-personal.umich.edu/~alandear/glossary/)

OECD (2006) *Economics Glossary: English-French* (2006)

Thomson Scientific *Glossary of Thomson Scientific Terminology*
(http://scientific.thomson.com/support/patents/patinf/terms/)