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Inciting Protocols – How International Environmental Agreements Trigger Knowledge Transfers

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Abstract

This paper studies patenting decisions by firms in relation to the negotiation and signing of the Helsinki and Oslo protocol as part of the Convention on Long-Range Transboundary Air Pollution. We use a uniquely constructed patent data set on SO_2 abatement technologies filed in 15 signatory and non-signatory countries in the period 1970-1997. The data distinguish between so-called 'mother' patents, or original inventions, and 'family' patents, which represent the same invention but are patents filed in foreign countries. Our analysis suggests that not only local environmental regulations matter for patenting decisions. International environmental agreements provide incentives for additional inventive activity in and the diffusion of knowledge towards signatory countries by reducing investment uncertainty for inventing firms.

Keywords: International environmental agreements, Inventions, Knowledge transfers, Patents, Acid rain

JEL Codes: D7; D8; O31; Q5

1 Introduction

This paper offers a new perspective on the currently dominant view that international environmental agreements (IEAs), such as the Convention on Long-Range Transboundary Air Pollution (LRTAP), have only little or even no impact on local efforts to reduce international environmental spillovers. Recent empirical and anecdotal evidence suggests that the LTRAP convention, which aims at reducing emissions in sulphur dioxide (SO_2) and nitrogen oxides (NO_X), has added little to what local governments were already planning to do (e.g., Levy, 1993; Murdoch and Sandler, 1997ab; Murdoch et al., 2003; Finus and Tjøtta, 2003). Even though IEAs in general may not be indicative for inducing emission reductions directly, we present evidence that the sulfur protocols under LRTAP have played a role on their own, albeit indirectly, by stimulating new inventions and their diffusion. Using a unique international patent data set, we show that the 1985 Helsinki protocol and the 1994 Oslo protocol changed the expectations of inventing firms in SO_2 abatement technologies about their market conditions, and therefore influenced both their inventive activity and their patent protection strategy.

We consider inventing firms' decisions about 'what to protect' and 'where to protect'. The 'what to protect' decision relates to the protection of new knowledge becoming available from inventing activities.[1] The 'where to protect' decision regards the decision in which other countries (besides the inventor's own country) the invention is worth to be protected. Both decisions are disentangled empirically by distinguishing between so called 'mother' and 'family' patents of the same piece of new knowledge (e.g., Lanjouw and Mody, 1996; Lanjouw and Schankerman, 2004). Using this distinction, we study the responsiveness of patenting behavior of inventing firms in SO_2 abatement technologies for signals such as those provided by IEAs, in particular the LRTAP convention as codified in the Helsinki and Oslo protocols signed in 1985 and 1994 respectively. An IEA is considered to provide a signal to inventors that affects their market expectations and, in turn, invention protection decisions. This signal is twofold. First, *negotiations* on the IEA signal that new, potentially more stringent regulations are likely to be introduced in the countries that participate in the IEA soon. We call this the run-up effect. Second, an IEA creates a more lasting signal, or permanent effect, if the agreement would guarantee a persistent demand for new inventions, i.e., provides an opportunity for inventing firms to sell their new inventions in the future. With such an IEA one would expect

[1] We define 'new knowledge' as original or modified inventions. Patents typically seek to protect such knowledge.

the demand for technologies to be persistently higher in signatory countries than in non-signatories after the signing of the protocol.

Our analysis is based on an innovative construction of a patent data set on SO_2 abatement technologies for 15 countries in the period 1970-1997. Several of these 15 countries did not cooperate under LRTAP. The period we study covers the phase-in period of LRTAP coordination for which the Helsinki and Oslo protocols are landmarks. We find clear indications that these protocols have indeed affected patenting behavior of inventing firms. In contrast to Popp (2006), we find indications that firms take the protocols' signaling effects into account. For instance, the Helsinki protocol stimulated German firms to continue their inventive activity even after its own national policy became effective. The protocol negotiations allowed German inventors to reap the potential benefits of their position as a technology leader at the time of the actual signing of the protocol. Knowledge diffusion decisions are also responsive to the establishment of the IEA to reduce SO_2-emissions. Family patents become more directed towards signatory countries both in the run-up period and after the establishment of a coalition. This finding is also robust to the observation that the value of mother patents (measured by the number of families for a given mother patent) increases after the negotiations started on the Helsinki protocol.

The next section provides a background analysis of our case study. Section 3 describes the local and international regulation of SO_2 emissions and our data collection procedure. Section 4 presents a first look at the (distribution of) patent counts. Section 5 describes the econometric model and section 6 presents the results for our main hypothesis. Section 7 examines endogeneity and identification problems as well as discusses some robustness issues. Section 8 concludes.

2 Inventions, knowledge flows and IEAs

Recent empirical evidence confirms the old Hicksian idea that inventions are triggered by changes in the relative prices of the factors of production (Hicks, 1932; Acemoglu, 2001). For example, Popp (2002) provides evidence that rising oil and gas prices induce patents for fossil-fuel saving technologies. Technology groups such as fuel cells, use of waste as fuel or for heat production, and coal gasification have clearly benefitted from the rise in fossil fuel energy prices over time. Similarly, environmental policy —whether implemented through a standard or a tax— enhances technological change because a policy program signals to (new) producers that it is beneficial to engage in R&D directed at meeting the requirements of the standard or at reducing tax payments. This is precisely what Popp (2006) found for the linkage between (local) emission standards for NO_X and SO_2 and patent counts of air pollution control equipment. In addition, Popp reports that firms in the most important inventing countries in these technological fields (the U.S., Germany and Japan) essentially responded to environmental regulatory pressure in their own country, but not to foreign environmental regulations.

Decisions to invest in new knowledge on abatement technologies and its (local and international) protection by patents are likely to be affected by actual local regulations (see Popp, 2006). We believe that *firms' expectations* about future local regulations are relevant too. Moreover, we expect that a well-designed IEA creates a signal to inventing firms about this development. Negotiations on (or the signing of) such an IEA (e.g., the Helsinki protocol), including changes of its existing rulings (e.g., the Oslo protocol), are likely to provide a (public) signal to inventing firms about opportunities for the profitable exploitation of their new or existing technologies. Not only will firms consider these new opportunities in their own country, but also in other countries, particularly in those countries that are participating in the negotiations and are therefore likely to become a signatory. Hence, our hypothesis is that IEAs induce more inventions in and direct the diffusion of these technologies towards the participating countries.[2]

The 'what to protect' decision is a decision on the protection of new knowledge generated by the firm and is embodied in the so-called 'mother patent', which is the original patent. Mother patents are usually filed in the home country of the inventor (or inventing firm). The inventing firm will also screen the option to protect its invention in other countries. Indeed, inventors can also file exactly the same patent in other countries up to one year after the filing of the mother patent. Patent applications designated to other countries are therefore referred to as family members of the mother patent. An inventor is likely to create a family of his nationally protected (mother) invention in other countries if the potential gains of protection in foreign markets are believed to outweigh its investment costs (Eaton et al., 2004).[3] The more countries in which a firm seeks to protect its new knowledge, the larger the (international) size of this market and the expected value of this new knowledge. Thus, family patents allow us to separate the decision of firms about 'what to pro-

[2] Note that the market size of a typical local invention in abatement technology is not restricted to the home country, but also depends on other countries introducing similar stringent emission restrictions as well (see also Acemoglu et al., 2009).

[3] Only Lanjouw and Mody (1996) and Lanjouw and Schankerman (2004) exploit the distinction between mother and family patents. The first paper illustrates that they indeed play an important role in the diffusion of abatement technologies to developing countries.

tect' from the one 'where to protect'. By distinguishing mother and family patents we are able to study not only whether the number or location of original inventions correlates with regulatory signals like local regulation or the signing of an IEA, but also whether the number and designation of the families of a given invention is sensitive to such events. Patent families can be characterized as intended knowledge flows, in contrast to patent citations, which are not made by the original inventor but by another inventor who builds on the original invention. Patent citations can be helpful when it comes to studying the international diffusion of knowledge (see Jaffe and Trajtenberg, 2002; Keller, 2004; Popp, 2006). However, patent citations are not instrumental to answer the questions that we wish to address.

Our hypothesis is that both the number of mother and family patents increases in the participating countries. One would expect such an effect *before* the actual signing of the introduction of an IEA. More specifically, we expect a run-up effect of IEAs on new inventions because IEA negotiations shift expectations ex-ante and provide an excellent opportunity for firms to influence market conditions in their own favor. In addition, the IEA could induce a stream of inventions as long as it provides a credible signal that demand for new inventions will continue to exist, i.e., provides an opportunity for inventing firms within signatory countries to sell its new inventions on a more permanent basis. Also the 'where to protect' decision is likely to be affected. We expect the IEA to influence the direction of family patenting behavior such that more family patents are likely to be observed in participating countries. As with mother patents, depending on the design and credibility of the IEA, we may also expect a more permanent increase in filed family patents in the participating countries. Finally, we expect the value of a given invention to rise —through a larger family size— due to the existence of an IEA.[4]

The patent data set we collected allows us to explore these potential effects of IEAs on the protection of new technologies and their designation by comparing differences in mother and family patent filing behavior of firms in both signatory and non-signatory countries in the years preceding as well as after the signing of the protocols.

[4]Note that family size is indeed as indicative of the value of a specific patent as patent citations (see Harhoff et al., 2003, p.1358). The mere existence of family members for a given patent as a measure of value has also been recognized by the use of so-called claimed priorities (see, for instance, Popp, 2006), which are patents that are claimed in at least one other country. Such patents would be more valuable than those that are protected in one country. However, this approach does not exploit the information contained in the number and designation of the patents.

3 SO_2 regulation and patent data

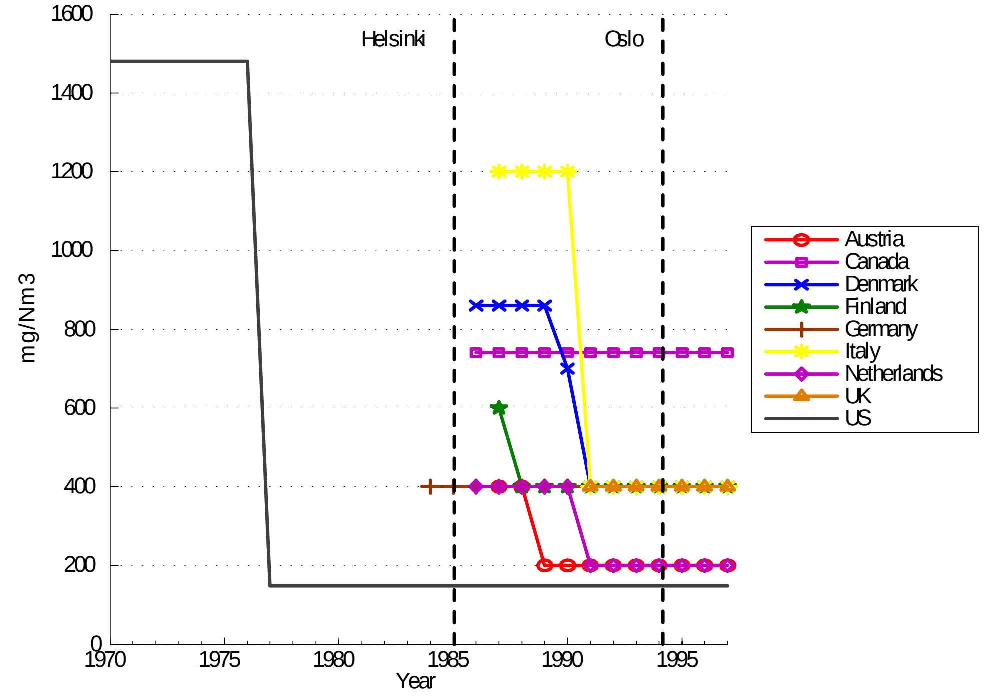
This section first discusses developments in both national and international regulation of SO_2 emissions and then explains our patent counts in detail.

3.1 Regulation of SO_2 emissions

Regulation of SO_2 emissions dates back to the late 1960s and early 1970s. At that time Japan and the U.S. took the lead with their implementation of regulatory schemes for coal-fired power plants. Already in 1968 Japan set emission standards that varied from plant to plant and the U.S. imposed a first limit on emissions in the Clean Air Act (CAA) in 1970. It took another decade before international cooperation was established under the auspices of the United Nations Economic Commission for Europe (UNECE). Individual interests of countries in cooperation may differ considerably due to large differences in the balance between imports and exports of acid emissions. Particularly Scandinavian countries and Canada suffered severely from acid rain in the late seventies, because their soils lack limestone. Hence, they were especially vulnerable to acid deposition (Barrett, 2003, p.7ff). Because acid rain crosses borders, a complex relationship exists between polluters and victims. Not only the prevailing western wind produced acid deposits in vulnerable areas, but sulfur imports also found their origin in Eastern European states.

The first international treaty was the Convention on LRTAP in 1979 (see Section 1). It provided the framework under which several protocols were established to regulate specific pollutants, starting with the reduction of sulfur oxides. At this time there was political reluctance to immediately enter into binding commitments to reduce emissions. With growing awareness of the seriousness of acid depositions in the early 1980s in Scandinavian countries, the Netherlands and particularly Germany, the political tide turned, leading to the Helsinki protocol —signed in 1985 and entered into force in 1987— on the reduction of sulfur emissions or their transboundary fluxes (Sliggers and Kakebeeke, 2004). For all signatories the reduction target for SO_2 emissions was 30% by 1994 compared to 1980 levels. The next major event that explicitly aimed to further reduce sulfur emissions has been its follow up protocol in Oslo in 1994. This 'Oslo Protocol on Further Reductions of Sulfur Emissions' introduced a differentiation of emission reduction targets (base year 1980) due to increased knowledge of the complexity of the international emission-deposition-damage chain as well as the aim to find cost-efficient emission reduction

Figure 1: Regulatory standards for coal fired power plants (in μgg/Nm3)



regulation.[5]

The countries in our data set that have been involved in coordinated effort from the beginning are Austria, Canada, Denmark, Finland, France, Germany, Italy, Luxemburg, the Netherlands, Sweden and Switzerland. Almost all participating countries ratified the Helsinki protocol already in 1987, which is also the year of enforcement (see Appendix A for further details). Ratification of the Oslo protocol has been more slowly and enforcement took effect in 1998. The UK and Poland participated only in the Oslo protocol, for which negotiations started in 1991. The UK was also involved in the negotiations on the Helsinki protocol, but in the end decided not to join. The U.S. and Japan kept out of cooperation under both the Helsinki and the Oslo protocol.

[5] The final event relevant for the specific regulation of SO_2 emissions is the Gothenburg protocol signed in 1999. This protocol is a comprehensive regulatory device that not only reduces acidification, but also eutrophication and ground-level ozone. It includes a differentiation of emission reduction obligations for 2010. The overall reduction target of SO_2 emissions in Europe amounts to at least 63% compared to 1990 levels. Ratification of the Gothenburg protocol has taken a lot of time with formal enforcement only in 2005. Because we have patent data only until 1997 we exclude the Gothenburg protocol from our analysis.

Abatement efforts for SO_2 emission reduction have been targeted predominantly at (coal-fired) power plants.[6] Figure 1 shows the stringency levels for a typical (large) coal-fired power plant as well as their timing for several countries in our data set in the period 1970-1997. As explained before, the U.S. and Japan (not in the figure) took the lead, but their regulations did not differ substantially in practice (see Popp, 2006, p.49).[7] Japanese standards were tightened by amendments in 1970 and 1974. Under the CAA the U.S. imposed a technology-forcing regulation in 1977 by requiring a 90% removal efficiency of SO_2 emissions for new power plants. This type of regulation was designed to ensure that the standards could basically be met by using flue gas desulfurization (FGD) technology rather than by switching to clean coal (e.g., Ackerman and Hassler, 1981). Thus, the environmental target was unchanged, but the government specified how to reach it.

The countries that decided to cooperate under the LRTAP framework in 1979, however, did not implement their first restrictions on emissions until the 1980s. It took until 1 June 1983 before Germany implemented emission standards for large plants (>50 MWt). The regulations in Germany were at a level of 400 mg/m^3 for new plants. The other signatory countries typically imposed their regulations in 1986 or 1987, i.e., *after* their own ratification of the Helsinki protocol, usually at less stringent levels compared to Germany. Except for the U.S., who maintained the advanced 1977 stringency levels, most of the countries in Figure 1 increased their stringency levels before the 1994 Oslo protocol, mainly by applying similar standards to existing and also smaller plants. In Germany, for instance, the scope of the original restriction of 400 mg/m^3 for new power plants was widened to existing plants in 1993.

3.2 Patent counts of SO_2 abatement technologies

Patent counts are usually obtained from selecting relevant patent classes where the classes themselves are further investigated by using keywords. As explained in detail by Popp (2006), the use of European Classification (ECLA), instead of the commonly used International Patent Classification (IPC) system, has the advantage

[6] We restrict ourselves to policies regarding power plants, because our patent counts are mainly linked to these regulations. Moreover, these regulations are easily comparable across countries. Popp (2006) offers a detailed account of policy interventions in the U.S., Japan and Germany. Information on country-specific regulation of coal-fired power plants has been obtained from Placet et al. (1988), Vernon (1988) and Sloss (2003). See Appendix A for further details.

[7] We exclude Japan from this graph because of its heterogeneous plant-by-plant regulations. Because of heterogeneity of country, type and capacity of power plants, the standards in the graph apply to large power plants (usually >300 MW).

that changes in classes over time are no longer problematic, because patents are reclassified as classes change.[8] Popp (2006) identified the relevant patent classes pertaining to pollution control by using keywords —in his case based on technological information on SO_2 and NO_X abatement technologies— which were extracted from various sources. Popp then subsequently screened some individual patent documents to assess the relevance of frequently occuring ECLA classes (see p.B2 of Appendix Popp, 2006).

We took a different approach in constructing our patent data set (see Appendix B for a detailed description). As Lanjouw and Mody (1996) note, the commonly followed procedure based on patent classes might suffer from the possibility to obtain patents which are not directly relevant for the specific field, and the possibility to loose relevant patents that are minorities in certain subclasses not selected by the keyword search. To minimize these errors, we fed the on-line database of the European Patent Office (EPO), *esp@cenet*, with keywords in order to identify all relevant *individual* patents. The keywords were extracted from SO_2 abatement technologies as explicitly described in the well-known RAINS model, developed at the International Institute for Applied Systems Analysis (see Cofala and Syri, 1998). We subsequently screened every single patent that came out of our search using *esp@cenet*. The patents we obtained in this way cover abatement technologies such as the use of low-sulfur fuels (including fuel desulfurization), in-furnace control of SO_2 emissions (e.g., through limestone injection or with several types of fluidized bed combustion), conventional wet flue gas desulfurization processes, advanced high efficiency methods for capturing sulfur from flue gas, and measures to control process emissions. These patents mainly represent efforts to reduce SO_2 emissions by coal-fired power plants.

The 'classification-based' search strategy performs rather differently relative to our keyword-based search strategy. Comparing our data with the number of counts reported by Popp (2006) for Germany, Japan and the U.S., we find remarkable differences. For these three countries the absolute levels are much higher with the classification strategy, in particular Japan. Furthermore, only for Germany the trend is similar given a correlation coefficient of 0.83 between Popp's total counts and ours. The much lower coefficient for Japan and the U.S., respectively 0.47 and 0.59, reconfirms Lanjouw and Mody's (1996) warning for classification errors.[9]

As a next step we distinguish mother and family patents based on their application and priority number. Family members, which protect exactly the same

[8] Nowadays also the IPC accounts for this.

[9] We thank David Popp for making his data available to enable this comparison.

invention as the mother patent, can be identified as having exactly the same priority numbers as the mother patent, but for which a different application number is used due to filing in another country. Additionally, our patent database consists of three types of patents: National patents (NP), European patents (EP) and International patents (WO). EP and WO are single patents, providing protection of intellectual property in multiple countries selected by the inventor.[10] To capture all knowledge flows we decomposed the EP and WO patents by assigning a count to each of the countries selected by the inventor in the year of filing the EP or WO patent. In order to prevent double counting, for instance when both a NP and an EP are filed for the same technology, we ranked the patents lexicographically in the above stated order. Hence, we registered knowledge flows covered by an EP only if they were not yet captured by national patents. The same holds for WO patents: these knowledge flows were registered only if protection was not yet granted through a NP or EP.[11]

Table 1 summarizes our counts and their distribution across countries for both mother and family patents separately. Not only the numbers differ considerably between countries but also the distribution across countries for mother and family patents. Together, Germany, Japan and the U.S. produced 92% of all mother patents, whereas only 26% of all family patents were filed in these three dominating countries. Hence, new inventions are concentrated in these three countries, of which only Germany has been involved in the SO_2 protocols. In contrast, family patents spread remarkably equal across the countries in our sample. As the bulk (70%) of the inventions can be found in non-signatory regions (Japan and the U.S.) it is hardly surprising that the share of family patents is much lower in these countries (27%).

4 A first look at the data

Figures 2 and 3 depict the overall efforts to protect inventions in SO_2 abatement technologies between 1970 and 1997 in both signatory and non-signatory countries through mother patents and their families, respectively. Quite different profiles emerge for mother and family patents in both signatory and non-signatory countries and across time. After an initial steep rise of mother patents in 1975,[12] the

[10] Note that EP and WO applications must still be acted upon by national patent offices.

[11] Some specific cases are discussed in appendix B.

[12] In a personal communication Matsuno argues that our counts for this period are probably too small due to language problems.

Table 1: Mother and family patent counts, 1970-1997

	Mother		Family	
	Total	Share (%)	Total	Share (%)
Austria	17	0.8	190	6.1
Canada	19	0.9	135	4.3
Denmark	10	0.5	121	3.9
Finland	16	0.8	65	2.1
France	19	0.9	308	9.9
Germany	483	23.6	299	9.6
Italy	8	0.4	278	8.9
Japan	933	45.6	241	7.7
Luxemburg	3	0.1	151	4.8
Netherlands	3	0.1	260	8.3
Poland	26	1.3	68	2.2
Sweden	9	0.4	211	6.8
Switzerland	3	0.1	164	5.3
United Kingdom	36	1.8	375	12.0
U.S.	460	22.5	257	8.2
Total	2045	100.0	3123	100.0
Signatory	603	29.5	2292	73.4
Non-signatory	1442	70.5	831	26.6

overall number of inventions starts to rise again sharply in 1981 and peaks around the Helsinki protocol. A second peak arises around Oslo, though less sharp. The patterns differ greatly between signatory and non-signatory countries, however. The sharp rise in mother patents in 1975 is explained almost only by activity in non-signatory countries, whereas the rise before Helsinki is largely attributable to the rise in patenting activity in the signatory countries. After Helsinki fewer and fewer new patents are filed in signatory countries, whereas inventive activity in non-signatory countries remains more or less stable in the late 1980s. In 1992 patenting activity starts to rise again in both signatory and non-signatory countries.

Figure 3 shows that the overall number of family patents is low on average before the Helsinki protocol and then rises sharply in the run-up to the signing of this protocol in 1985 and remains high afterwards. Peaks occur around 1987 as well as in 1995, just one year after the signing of the Oslo protocol.[13] The difference in patenting activity between the signatory and non-signatory countries is less remarkable than in the case of mother patents. The number of family patenting

[13] As expected, the peaks for family patents are somewhat later compared to mother patents because of the available time lag of 12 months that applies to filing such patents relative to their mother patents.

Figure 2: Mother patents in signatory and non-signatory countries

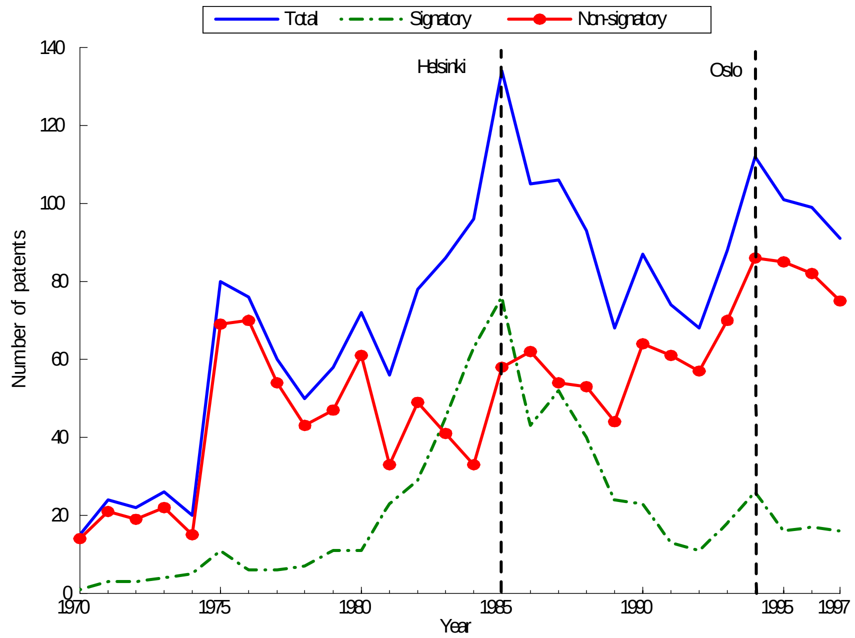


Figure 3: Family patents in signatory and non-signatory countries

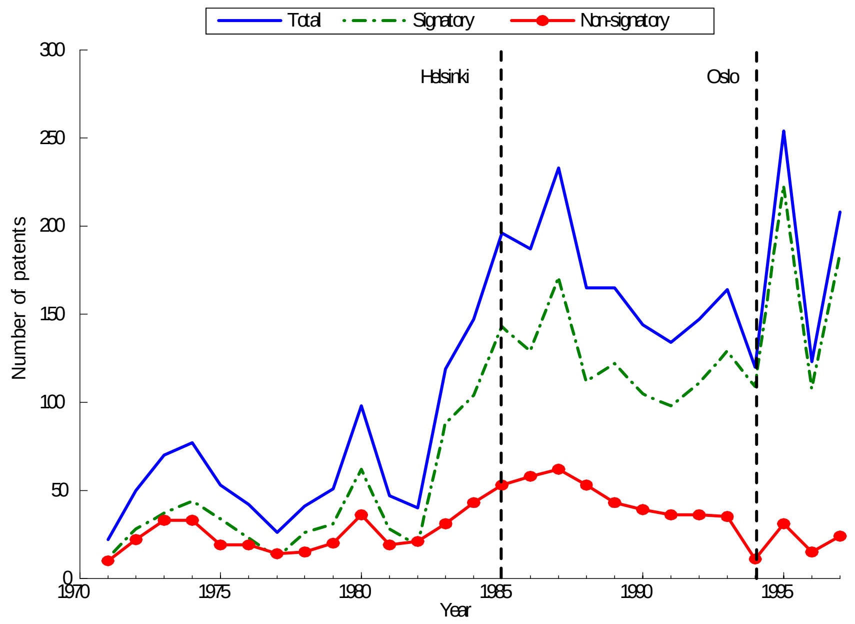


Figure 4: Ratio of region specific family patents to all one year lagged mother patents

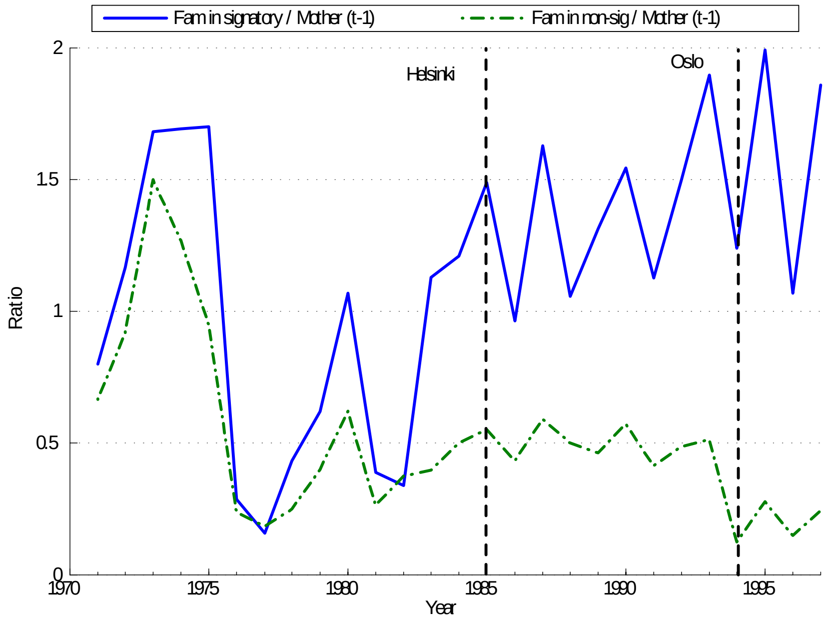


Figure 5:

in signatory countries grows fast in the run-up period to Helsinki and remains high thereafter. We do not observe a similar increase of family patenting activity in the advent to Oslo, but the activity level remains high despite its erratic pattern at the end of our observation period. One could argue that if protocols would stimulate mother patents, then any increase in patent families would occur, just because more mother patents are available for designation abroad. Figure 4 shows, however, that this is unlikely by depicting the difference in the ratio of family patents to one-year lagged mother patents in signatory versus non-signatory countries.[14] Both series exhibit a similar pattern until 1983 but then start to diverge strongly.[15] This suggests that even if the Helsinki protocol would have promoted more mother patents, the decision to file family patents is also affected. Indeed, the value of a new invention, as measured by the number of families relative to a mother patent in signatory countries, has increased strongly after the negotiation and signing of the Helsinki

[14] We apply a lag since family patents can be filed within one year from the mother patent.

[15] The high level of the ratio in the first half of the 1970s is due to the increase in filed Japanese mother patents. The peak around 1980 is related to the signing of the non-binding agreement under the LRTAP.

protocol.

Our data suggest a clear effect of the international negotiations on SO_2 abatement technologies. Mother patents peak around both protocols in both signatory and non-signatory countries. Family patenting rises in signatory countries before the signing of both protocols —though to a lesser extent around Oslo— and remains persistently high after Helsinki. This is at variance with the claim by Popp (2006) that only domestic environmental policy determines patenting by domestic firms. Naturally also local regulatory interventions play a role. For instance, the big spike in the mid 1980s in signatory countries is largely attributable to German patents, which is likely to be influenced by new German legislation for coal-fired power plants in 1983. Also the U.S. introduced the Clean Air Act (CAA) in 1990 announcing its emissions trading program to be phased-in in 1995. This more or less coincides with the signing of the Oslo protocol in 1994. In the sequel we therefore control for local regulation in our econometric analysis.

5 Econometric specification and estimation

In this section, we present the econometric model to test whether a differential effect of patent filings in both signatory and non-signatory countries exists in relation to the establishment of the Helsinki and Oslo protocol. The dependent variables are the aggregate numbers of the filed mother and family patents in the 15 countries between 1970 and 1997.[16] We study both run-up and permanent effects by modelling the Helsinki and Oslo protocols on SO_2 abatement as event variables. As explained before, the run-up effect accounts for forward looking behavior by inventors during the negotiation process whereas the permanent effect has to do with additional patenting beyond the implementation of the protocols.

Because both our dependent variables are counts of filed patents, we apply a conditional fixed effects Poisson panel model.[17] We assume the following conditional

[16] Note that we do not model patent filings by country of origin. We restrict our econometric analysis to the *total* amount of mother or family patents on SO_2 abatement in a given country. These patents might originate from both domestic and foreign firms. However, our distinction between mother and family patents implicitly accounts for origin and designation, because mother patents are typically filed in the inventors' *own* countries and family patents in *other* countries. Also the distribution across countries of both mother and family patents is asymmetric as described in subsection 3.2.

[17] A similar approach is used by Acemoglu and Linn (2004). See Wooldridge (2002), p.674ff for details on the estimation strategy.

mean function for the SO_2 abatement patents:

$$E\left[P_{it}|c_i,\theta_t,\mathbf{X}_{it}\right]=\exp(c_i+\theta_t+\gamma\cdot\mathbf{X}_{it}+\delta\cdot RUNUP_{it}+\phi\cdot PERM_{it}),\qquad(1)$$

where E is the expectations operator, P_{it} is the number of mother (or family) patents filed in country i in year t, c_i represents country fixed effects, θ_t specifies year effects capturing any common time component and the vector $\mathbf{X}_{it}$ contains country-specific control variables, to be discussed below.

Our main variables of interest are the event (dummy) variables $RUNUP$ and $PERM$, which respectively reflect the potential effects of patent filings in the advent to the signing of the protocol and its permanent impact. We define $RUNUP$ to be equal to one for signatory countries in the years of the actual signing of the Helsinki and Oslo protocol as well as during a predefined anticipation period. Furthermore, we allow for asymmetric impacts of the Helsinki and Oslo protocol and control for their individual effects separately. We study the permanent effect by the separate variable $PERM$ which equals one in the signatory countries for the whole period after the signing of the Helsinki protocol. We estimate (1) with $RUNUP$ and $PERM$ separately as well as jointly.

To identify differences in patent filing behavior between firms in signatory and non-signatory countries we estimate both variables by using a difference-in-difference approach. To get rid of unobserved heterogeneity represented by the country fixed effects in our panel estimation we follow Hausman et al. (1984). We accordingly factor out the heterogeneity component (c_i) through the conditional logit transformation to obtain a multinomial distribution for P_{it} of the form:

$$E[P_{it}|\theta_t,\mathbf{X}_{it},\bar{P}_i]=\frac{\exp\left(\theta_t+\gamma\cdot\mathbf{X}_{it}+\delta\cdot RUNUP_{it}+\phi\cdot PERM_{it}\right)}{\sum_{\tau=1}^{T}\exp\left(\theta_\tau+\gamma\cdot\mathbf{X}_{i\tau}+\delta\cdot RUNUP_{i\tau}+\phi\cdot PERM_{i\tau}\right)}\bar{P}_i,\quad(2)$$

where $\bar{P}_i=\sum_{t=1}^{T}P_{it}$ is the total number of filed patents in country i over the entire sample period. This transformation allows consistent estimation of our main parameters of interest (δ and ϕ) by applying Quasi Maximum Likelihood. These parameters show the expected percentage change in patent filings in the signatory countries as opposed to not being a signatory country in that year. We estimate (2) using robust standard errors.

If the protocols have a differential effect on the number of mother and family patents filed in signatory countries, we expect δ and/or ϕ to be positive and significant. The exact timing of the anticipation period associated with the run-up effect is open and ultimately depends on the forward looking behavior of the inventing firms. For instance, we expect that the technology seminars organized by LRTAP have played an important role. With a 5-year interval, starting in May 1981 in Salzburg (Austria), these technology seminars reviewed available control technologies (Sliggers and Kakebeeke, 2004). Moreover, they also integrated technical knowledge into the protocols' annexes, such as the flue gas desulfurization technology in 1981. By defining the important types of technologies a signal was provided to innovators on potential directions to explore in their research programs and/or designate protection of existing inventions across different (participating) countries. The timing of these seminars (1981, 1986 and 1991) is such that a lag of more than 3 years is unlikely. We focus on a 2 year lag and set our event dummies equal to one in 1983-1985 and 1992-1994 for only those countries that actually signed the Helsinki and Oslo protocol (see Table 2). We conduct robustness tests of our results with alternative specifications of the length of the event variable. For the models that evaluate a permanent effect of the signing of the protocols in signatory countries, we set the variable $PERM$ equal to one for the whole period after the signing of the Helsinki protocol, i.e., 1986-1997.[18]

Table 2: Treatment dummy for signatory countries ($RUNUP$) in anticipation to the signing of the protocols

	Dummy Helsinki	Dummy Oslo
Austria	1983-1985	1992-1994
Canada	1983-1985	1992-1994
Denmark	1983-1985	1992-1994
Finland	1983-1985	1992-1994
France	1983-1985	1992-1994
Germany	1983-1985	1992-1994
Italy	1983-1985	1992-1994
Japan	No	No
Luxemburg	1983-1985	1992-1994
Netherlands	1983-1985	1992-1994
Poland	No	1992-1994
Sweden	1983-1985	1992-1994
Switzerland	1983-1985	1992-1994
United Kingdom	No	1992-1994
U.S.	No	No

As country-specific control variables we employ, first of all, the share of coal-based electricity in total electricity (labeled $COAL\ SHARE$). Countries with a high coal

[18] For the UK and Poland the dummy is equal to one for 1995-1997, i.e., the years after they became a member of LRTAP.

share are more likely to impose tighter restrictions and therefore seem to be targeted first by firms seeking protection of their new inventions. Furthermore, we include the overall number of patents for all types of technologies (labeled $TOTAL\ PATENTS$) filed in each country as a scaling variable. Countries may differ systematically in rates of acceptance of patent applications, in how much research they do or — given the amount of inventing activity— how active firms are in patenting. In the estimations for the family patents we add a separate variable (labeled $LAGGED\ MOTHER\ OTHER$) that controls for all new knowledge (both within signatory and non-signatory countries) that became available *outside* a specific country, say i, for designation into this country i in the year before the family itself was actually filed, i.e., $\mathbf{X}_{-it-1}$. Table 3 provides some descriptive statistics for our dependent and control variables.

Table 3: Descriptive Statistics, 1970-1997

Variable	Number	Unit	Mean	St.Dev	Min	Max
Mother patents	420	count	4.87	11.62	0	69
Family patents	405	count	7.71	6.34	0	26
Coal share	420	% electricity production	0.34	0.30	0	0.97
Total patents	420	count (1,000)	3.78	6.99	0	34.73
Lagged mother other	405	count	67.55	30.60	3	134

6 Main results

For *mother* patents the first column of Table 4 provides evidence for a significant upward run-up effect for new inventions in signatory countries of the Helsinki protocol. The absolute number of mother patents rises in signatory and non-signatory countries in both run-up periods (see Figure 2), but the likelihood to observe additional patent filings in the signatory countries is considerably higher around Helsinki. The expected number of filed mother patents in signatory countries during the run-up period before Helsinki increases by 147%. For the Oslo protocol the effect is negative, though not significant at the 10% level.

Key to the correct identification of an independent effect of the protocols is to control for local regulation. Therefore, column 2 presents results of a specification that controls for major changes in local environmental policy in the main inventing countries — Germany and the U.S.— around the signing of the protocols. Assuming the same anticipation period for inventions as for the protocols, we set these dummies equal to 1 for Germany in the period 1981-1983, since Germany tightened local regulation in 1983, and equal to 1 for the U.S. in the period 1993-1995 because of the introduction of the CAA in 1995. The results confirm, first of all, Popp's (2006) finding that local regulation induced new inventions in Germany. But we find in addition evidence of a strong positive run-up effect for Helsinki. Inventive activity in Germany continued even after its local regulation was already enforced, i.e. during the run-up period to Helsinki. Furthermore, we still find a positive run-up effect for Helsinki when the main inventing signatory country Germany is excluded from the sample, although the effect is smaller. Thus, the Helsinki protocol also had an effect on inventors in other small inventing signatory countries outside Germany (see column (3)). Clearly coal share has no effect in the specifations including Germany, but column (3) indicates new inventions are more likely to take place in countries with a high coal share.

Table 4: Two year lag effect of protocols on mother patents

	(1)	(2)	(3)	(4)
		Incl local policy	Excl GER	Permanent
Run-up Helsinki	1.47 (0.15)***	1.41 (0.15)***	0.85 (0.35)**	1.85 (0.34)***
Run-up Oslo	- 0.35 (0.22)	- 0.41 (0.22)*	0.04 (0.29)	- 0.47 (0.24)*
Permanent				0.86 (0.47)*
Policy Germany		0.54 (0.16)***		0.68 (0.26)***
Policy U.S.		- 0.33 (0.08)***	- 0.28 (0.09)***	- 0.18 (0.12)
Coal share	- 0.38 (1.83)	- 0.80 (1.87)	1.59 (0.91)*	1.21 (1.76)
Total patents	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	0.02 (0.02)
Log likelihood	-608	-600	-466	-589
Number of obs.	420	420	392	420
Groups	15	15	14	15

Standard errors within parenthesis. ***[**](*) denotes significance at the 1[5](10) percent level

Our findings for the Oslo protocol are very different compared to Helsinki. Even though we observe a peak in mother patenting activity in signatory countries in 1994 (see Figure 2), our estimates reflect no evidence of additional activity within the signatory countries relative to the non-signatory countries. Instead, we find a weakly negative effect for the run-up effect in the signatory countries as well as a strongly significant *negative* correlation with the U.S. policy dummy around that time. Mother patenting activity in the advent to both Oslo and the new CAA regulation on emissions trading in the U.S. in 1995 is mainly concentrated in Japan.

Both the observed upward effect in Germany and the U.S. pales into insignificance compared to the additional activity in Japan before and in 1995. Given these trends in the three major inventing countries it is hardly surprising that we do not find any effect for the Oslo protocol.[19]

We conclude that the run-up effects for new inventions visible in Figure 2 seems to be at least partly triggered by the negotiations on the protocols. In particular, the peak in 1985 (Helsinki) in signatory countries cannot be explained by changes in local regulation only. For the renewal of the protocol in 1994 we do not find such evidence. Indeed disentangling the impact of the protocol in 1994 and changes in U.S. policy in 1995 is less clear. Moreover, the number of mother patents in non-signatory countries, in particular Japan, grew even faster than those in signatory countries since 1992. This suggests that inventors *outside* signatory countries may also respond to credible announcements of regulation in countries that participate in a joint effort to reduce emissions.

We have also tested whether a permanent effect can be observed in addition to the run-up effect for mother patents. Column (4) in Table 4 provides some evidence for this hypothesis, but the evidence is weak. Moreover, this effect is mainly due to German inventors, for which the number of filed mother patents actually gradually declined in the late 80s. Also the gradual shift in inventive activity towards Japan affects the identification of a permanent effect.

The estimates for the *family patents* in the run-up period provide evidence for the hypothesis that IEAs improve market conditions for new inventions: the expected number of filed family patents in signatory countries in the years before and the year of the signing of Helsinki increases by 28% on average and even 69% for Oslo (see column 1 in Table 5). An indication that family patents spread to countries that do not have a large inventive sector is the negative correlation with the total number of patents filed in specific countries. As expected, the number of filed family patents in a country increases if additional mother patent activity takes place in other countries. Again coal share has no significant effect in this simple specification. We also estimated the model with policy dummies for local regulation in Germany in 1983 and U.S. regulation in 1995. The results for our main variables of interest are almost entirely similar (see column 2 in Table 5). Somewhat surprisingly, we find evidence for significantly less family patenting in the years before the major

[19] Note also that the results for the Oslo protocol are in concordance with Popp's (2006) observation that Japanese patents were the only case where foreign patents were increasing when U.S. regulations tightened. However, the additional activity in Japan could also (or in addition) be triggered by an expected increase (in stringency) of regulation in signatory countries.

change in U.S. regulation. This is mainly explained by the peak of family patents in signatory countries in 1995, which is not covered by the run-up dummy.

Table 5: Two year lag effect of protocols on family patents

	(1)	(2) Incl local policy	(3) Permanent
Run-up Helsinki	0.28 (0.12)**	0.28 (0.12)**	0.48 (0.18)**
Run-up Oslo	0.69 (0.15)***	0.62 (0.12)***	0.59 (0.12)***
Permanent			0.31 (0.15)**
Policy Germany		- 0.02 (0.09)	- 0.01 (0.09)
Policy U.S.		- 0.24 (0.10)**	- 0.19 (0.10)*
Coal share	0.98 (0.65)	0.98 (0.65)	1.17 (0.78)
Total patents	- 0.05 (0.02)***	- 0.05 (0.02)***	- 0.04 (0.02)**
Lagged mother other	0.01 (0.00)**	0.01 (0.00)**	0.01 (0.00)***
Log likelihood	-917	-917	-887
Number of obs	405	405	405
Groups	15	15	15

Standard errors within parenthesis ***[**](*) denotes significance at the 1[5](10) percent level.

In addition to the significant run-up effects for both protocols, we also find evidence for a significant permanent effect within the signatory countries (see column 3 in Table 5). Note that the loglikelihood of the latter specification is much improved. These findings again suggest that inventors not only respond to policy signals in their own country, but also consider the protocols to provide credible signals of increasing demand for abatement technologies in other signatory countries.

The general picture that emerges is that the IEAs have explanatory power for both the development of new inventions as well as for their international diffusion. The Helsinki protocol is strongly correlated with additional activity in both mother and family patents within signatory countries before its signing also if we control for local policies and the overall number of new inventions outside the designated countries. For the Oslo protocol we do not observe an increase in mother patenting in signatory countries, but the number of designated family patents in signatory countries as well as the permanent effect on the overall number of families since Helsinki illustrates the relevance of IEAs for inventors in making their protection decisions.

7 Identification problems and robustness analysis

Several issues deserve closer scrutiny. Our hypothesis is that firms respond to changing prospects induced by a credible IEA. The IEA either serves as an early signal of upcoming (more) stringent regulation and/or turns the cooperating countries into a (relatively) attractive market. One might wonder, however, whether not the same amount and distribution of innovation would have occured were the treaties never adopted. One reason could be that only countries that had a clear interest in the IEA decided to participate, e.g. to benefit from the pool of knowledge, and those who had no such interest simply did not join. A second reason is that simultaneity problems complicate separating the effect of the IEA from local regulatory effects. Finally, institutional differences in the propensity to patent and alternative controls could also affect our results. We will address these three issues below.

7.1 Endogenous participation decisions

It is hard to belief that our results suffer from selective participation decisions by countries. If anything we learn from our distinction between mother and family patents, it is that inventing *firms*, not countries, are responsive to changing market conditions. Firms consider an IEA as an early signal of upcoming regulations in participating countries or — depending on the credibility of the IEA — as a continuous signal for a lasting market. However, *countries* make their participation decisions in relation to whether or not they can organize reduction commitments properly. Victim countries try to commit polluters, which is complicated if the externality is not bilateral, such as in the case of the UK.

Furthermore, endogeneity is likely to be a problem if patterns between non-signatory and signatory countries are very different before the event. This is clearly not the case for family patents, but might be relevant for mother patents (compare Figures 2 and 3). However, participation in the IEA is by no means a necessary condition to directly benefit from the options provided by the coalition. Inventing firms outside the coalition, like those in the U.S. and Japan, can always use families to protect their new inventions inside the coalition. And this is exactly what is illustrated by the diverging pattern between the inflow of family patents in signatory and non-signatory countries after the negotiations on the Helsinki protocol started (and which is confirmed by our variable $PERM$ in Table 5 column (3)).

Further evidence against our analysis being perverted by endogeneity problems comes from the U.K. If the goal would have been access to the knowledge pool, the

UK should have signed for sure because of its large share of coal-based electricity generation. In fact, the UK did not sign the Helsinki protocol and only decided much later to participate in the Oslo protocol. Also serious stringent local regulation of coal-fired power plants had to wait until 1991 when the UK was obliged to implement the EU Coal Combustion Plant Directive. One of the main reasons behind the UK's weak incentives to commit was that most of its SO_2 emissions were transported out of the UK whilst very little SO_2 emissions entered into the UK from abroad. In addition, on a more domestic level, around the timing of the Helsinki protocol the UK was also considering to privatise the electricity sector and its future energy requirements were uncertain (see Albin, 2001, p.69).

Furthermore, closer inspection of our data also suggest that participation in the Helsinki protocol was not necessary at all to get access to the knowledge pool. The mother patent data show that inventive activity was always present in the UK in the pre-Helsinki period (see Figure 5). Only when it became clear that the UK did not participate in the Helsinki protocol, new patents were no longer filed. Furthermore, inventors abroad always included this country in their knowledge protection considerations. The number of family patents in the UK was always highest of all countries in our data set and also closely followed the trend in other signatory countries (see Figure 5). The UK remained an important target, because the 1988 EU Large Combustion Plant Directive made it plausible that the country had to adapt its policies anyway. These observations are confirmed when we re-estimate our basic specification with the UK included as a signatory country.[20]

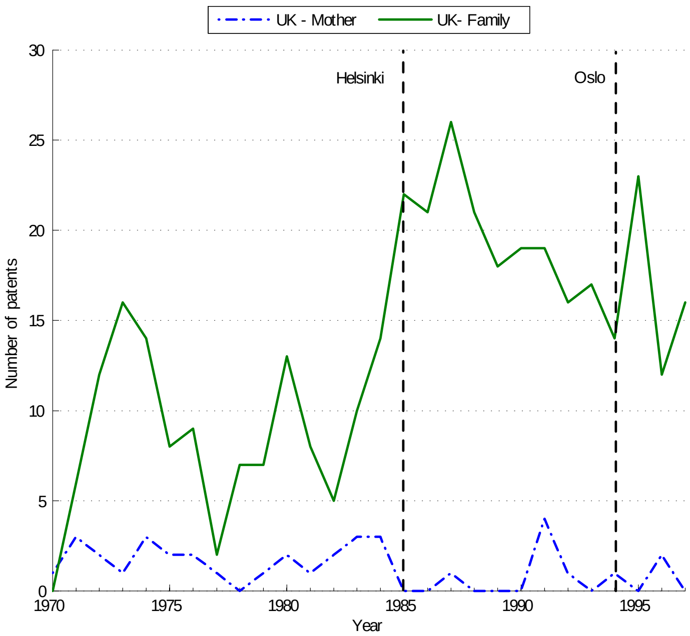
7.2 IEA versus regulatory effects

To identify the IEA effects as separate from and additional to local regulatory effects our basic specification already controls for the major local policy effects in countries that host most important inventors, typically Germany and the U.S.,[21] as well as a coal share variable as a proxy for (anticipated) local policy effects in other countries. An alternative way to potentially control for this problem is using ratification dates as a proxy for the introduction of (anticipated) more stringent local regulation. Appendix A shows that in particular ratification for Helsinki is a good proxy for increased local stringency. Ratification often occurs in the same or one year before the introduction of more stringent local measures.

[20] This only has a small effect on the coefficients and never changes our findings in a fundamental way. Also excluding the UK from our sample has no significant effect on the results (results available upon request).

[21] Note that Japan's regulatory environment is much different (compare Immura, 2005).

Figure 6: The filing of mother and family patents in the UK



We therefore constructed a 'ratification' dummy. This dummy allows for inventing firms anticipating local regulation to become more stringent only after ratification, and not because a country negotiates and signs the IEA as such. For this purpose we use country-specific information on the year of ratification by the protocol participants applying the same two-year anticipation period. For instance, the run-up dummy for Austria is equal to one in the years 1985-1987, respectively 1996-1997, because Austria ratified the Helsinki protocol in 1987 and the Oslo protocol in 1998.

Interestingly, the estimations based on this ratification dummy indeed generate smaller and less significant results compared to the earlier IEA effect based on the pre-negotiation period (see columns 1 and 2 in Table 6).[22] For mother patents we still observe a significant and positive effect for Helsinki but the effect is much smaller. The run-up effect for Oslo is still strongly negative and significant whereas the permanent effect no longer obtains. Apparently inventors already anticipated upcoming changes in local regulation in signatory countries during the negotiation process and did not wait for the ratification process. Similar results obtain from our

[22] Note that the loglikelihoods for all our estimations with the ratification dummy are lower than for our basic models. Also the marginal effects are lower.

estimates for family patents (see columns 3 and 4 in Table 6). Still a significant, but smaller run-up effect exists for ratification after Helsinki and both the run-up effect for Oslo and the and permanent effect are no longer significant. We conclude that our hypothesis that negotiation processes on protocols have a role on their own makes more sense than to assume that inventing firms anticipate stricter local regulatory interventions that come about 4 to 5 years later.[23]

Table 6: Robustness analysis

	(1)	(2)	(3)	(4)
Dependent Variable	Mother Patents Ratification	Mother Patents Ratification	Family Patents Ratification	Family Patents Ratification
Run-up Helsinki	1.17 (0.10)***	1.16 (0.10)***	0.21 (0.09)**	0.21 (0.09)***
Run-up Oslo	- 0.68 (0.16)***	- 0.68 (0.18)***	- 0.06 (0.12)	- 0.06 (0.12)
Permanent		- 0.24 (0.27)		0.15 (0.10)
Policy Germany	1.11 (0.11)***	1.03 (0.16)***	0.05 (0.09)	0.07 (0.09)
Policy U.S.	- 0.25 (0.15)*	- 0.30 (0.16)*	- 0.52 (0.11)***	- 0.47 (0.10)***
Coal share	- 0.56 (1.42)	- 1.11 (1.70)	0.97 (0.62)	1.05 (0.69)
Total patents	- 0.00 (0.01)	- 0.01 (0.02)	- 0.05 (0.02)***	- 0.04 (0.02)***
Lagged mother other			0.01 (0.00)***	0.01 (0.00)***
Log likelihood	-607	-605	-921	-919
Number of obs.	420	420	405	405
Groups	15	15	15	15

Standard errors within parenthesis. ***[**](*) denotes significance at the 1[5](10) percent level.

A related issue is the choice of the length of the event dummy representing the negotiation process itself. The choice of a two-year lag seems somewhat arbitrary, because we do not exactly know how and when policy signals affect inventors. Therefore we ran several alternative specifications using longer or shorter lag lengths, i.e., three years and one year respectively.[24] For the longer window of anticipation we find fairly similar results for mother, but not for family patents (see Table 7).[25] In the estimations for mother patents only the local policy dummy for Germany is no longer significant, which is likely to be explained by the overlap with the Helsinki

[23] Note that the stringency of the local standards themselves are also likely to be conditional on the IEA itself. However, whether or not the Helsinki protocol has lead to stricter local regulations than those that would have been obtained under unilateral action is still an open question (see Barrett, 2003).

[24] In the three (one) year lag model we set our event dummy equal to one in 1982-1985 (1984-1985) and 1991-1994 (1993-1994) for all countries that signed the Helsinki and Oslo protocol.

[25] For the one year lag model nothing of importance changes either whether or not we test with or without the inclusion of Germany.

run-up dummy in 1982 and 1983.[26] In contrast, our family patent estimates now show **much smaller and less significant** effects. As one might expect, the effects on the 'where to' protect decision become stronger when the protocol date comes closer and the likelihood of an agreement increases.

Table 7: Robustness analysis

	(1)	(2)	(3)	(4)
Dependent Variable	Mother Patents Lag 3	Family Patents Lag 3	Mother Patents Scaling Japan	Family Patents Excl DK/FIN
Run-up Helsinki	1.36 (0.14)***	0.35 (0.19)*	1.28 (0.18)***	0.58 (0.17)**
Run-up Oslo	- 0.41 (0.20)**	0.53 (0.06)***	- 0.38 (0.24)	0.58 (0.13)***
Permanent		0.26 (0.17)		0.37 (0.16)**
Policy Germany	0.00 (0.13)	0.08 (0.10)	0.59 (0.18)***	- 0.07 (0.08)
Policy U.S.	- 0.33 (0.09)***	- 0.22 (0.08)***	- 0.16 (0.16)	- 0.13 (0.10)
Coal share	- 0.67 (1.87)	1.11 (0.77)	- 2.25 (1.95)	1.27 (0.89)
Total patents	- 0.00 (0.01)	- 0.04 (0.02)**	0.00 (0.02)	- 0.03 (0.01)**
Lagged mother other		0.01 (0.00)***		0.01 (0.00)***
Log likelihood	-607	-914	-523	-783
Number of obs.	420	405	420	351
Groups	15	15	15	13

Standard errors within parenthesis. ***[**](*) denotes significance at the 1[5](10) percent level.

7.3 Differences in institutional rules in patent protection

A final issue are institutional differences in the legal protection of ideas across countries. In Japan, for example, every claim needs to be filed as a separate patent, whereas in other countries a single patent can hold several claims.[27] This might give rise to a disproportionally large number of Japanese patents and cause biased results. Eaton and Kortum (1999, p.542) estimate that the filing of patents in Japan is 5 times as large as elsewhere. If we divide the number of Japanese mother patents by 5 and re-estimate our basic specification, we only observe minor changes in our results (see column 3 in Table 7).

Another concern is that the overall number of family counts might be affected by the growing importance of so-called European patents (EP) and international

[26] This illustrates the risk of overidentification if too many overlapping time dummies are included in the estimations. Further experimentation with the cross-section without Germany confirms our previous results. The negative effect for Oslo is still entirely due to the observed (lack of) filing of mother patents in Germany in this period and simply disappears in this case. Results are available on request.

[27] The problem only exists for mother patents.

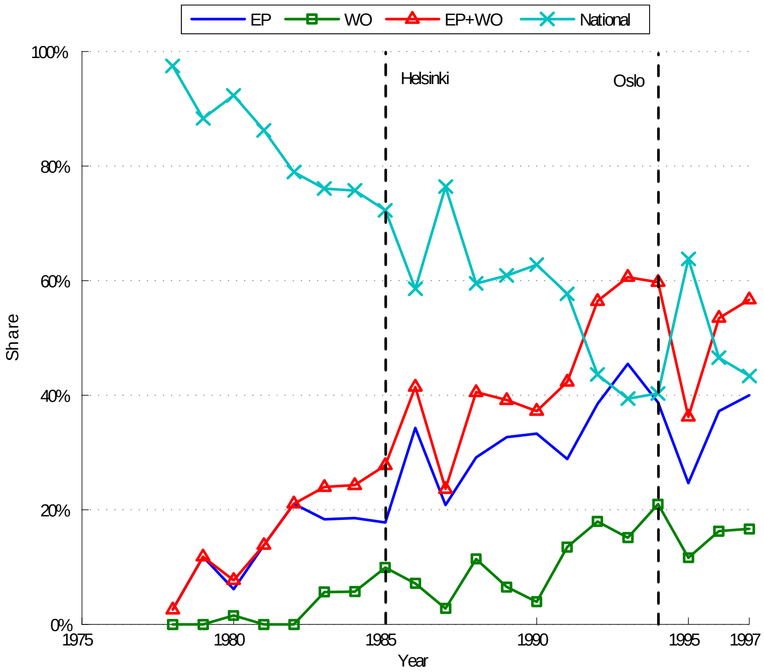
patents (WO) (see Section 3.2). For example, an EP patent granted by the Dutch patent office guarantees protection in a number of selected member states (i.e., indicated/selected by the inventor) of the European Patent Convention (EPC) or Patent Cooperation Treaty (PCT) within Europe. Due to these treaties, seeking protection in multiple countries has become cheaper. According to Eaton et al. (2004) the number of EP publications grew with 70% between 1991 and 2000, whereas also the number of destinations designated for protection in a typical EP ('family size') has grown substantially in this period.

Because we treat the family members of an EP as separate counts and all of our sample signatory countries except one (Canada) are located in Europe, we face two potential biases. First, the observed increase in the number of filed family patents, which we attributed to the IEA negotiations and signing, may have been (partially) caused by the reduction in costs of filing additional family patents. Second, if more countries join the patent treaties one expects an increase in the average size of patent families due to the reduction in marginal protection costs and not because of the incentives provided by our main events. For instance, Denmark and Finland signed the EPC respectively in 1990 and 1996 and both countries show a strong increase in filed family members afterwards.

The filing of EP and WO patents has been possible since the late seventies. We observe the first EP and WO patents in our data base in 1978. Until the mid 1990s the number of EP and WO patents has increased steadily (see Figure 5). During the entire sample period the share of EP and WO patents never went beyond 60% of all of our family counts. In total 287 EP and 97 WO patents have been filed up to 1997, whereas we found 756 family patents filed at national offices.[28] Even in 1997 still 26 of an overall number of 60 abatement technologies were filed at the national offices, whereas only 24 were EP and 10 WO. Moreover, the number of nationally filed family patents in the U.S., Canada and Japan fluctuates around 60% already since the early 1980s. These observations support the Eaton et al. (2004) findings that the growth in EP publications was not at the expense of patents sought directly through national patent offices. The increase in the share of the overall number of EP and WO patents is quite strong in the periods 1981-1986 and 1991-1994 followed by steep declines in both cases. These periods coincide with the advent to Helsinki in 1985 and Oslo in 1994. This development is in stark contrast with the much more gradual penetration pattern for all EP patenting as described by Eaton et al. (2004).

[28] Given that our overall number of family counts is 3,123 simple arithmetics learns that these 384 (287+97) EP and WO patents account in total for 2,367 family members, or 6 designated countries on average.

Figure 7: Share of EPO and WO patents in overall counts



Hence, the protocols may have acted as an additional trigger for EP in this specific technology subfield. If firms seek protection for their inventions in foreign countries, they are likely to exploit opportunities to reduce their cost of protection. And this is precisely what EPs offer. Moreover, most European countries cooperating through the protocols also participated in the EPC treaty.

Even if EPs and WOs have not entirely substituted for national patent offices filings, their likely effect on family size of a given invention may still give rise to some concern. In the late 1990s a number of factors induced the 'movement to universality' in Europe (Eaton et al., 2004). By 2000 most EPs designated all EPO members for protection. Fees for a given EP fell dramatically in 1997 with 33% reduction for a single EP and a 50% for the cost of each additional country designated for protection. Moreover, since 1999 no additional fees are levied for EPs designated for over seven EPO members. So it is hardly surprising that Eaton et al. (2004) find evidence that the tendency to universality can be explained by these price changes. With our sample period ending in 1997, these factors are unlikely to have biased our results. Indeed, only at the end of our sample period (1995-1997) we find some evidence of a co-movement of European family patents. Even then significant differences in the number of family patents applied in different EPO member states remained. As a final check we estimated our basic specification without Denmark and Finland in the sample, because they joint the patent treaties during the sample period. Our main conclusions are not affected (see column 4 in Table 8).

8 Conclusions

This paper supports the idea that IEAs can provide important signals for firms to invest in new technologies as well as to protect their inventions abroad in anticipation to changes in market size in the nearby future. Firms anticipate the potential benefit of such international agreements and exploit the advantages of the protocols for their market expansion through the designation of their family patents. IEA negotiations cast their shadows even before they become operational and more stringent policy measures are implemented. Our analysis of SO_2 abatement technologies illustrates that inventing firms respond to expected changes not only to local but also to changes in international environmental policy.

Although our main result differs from Popp (2006), the two studies also complement each other. First of all, our unique set of patent counts confirms the inventive dominance of the three major countries in flue gas desulfurization technology —the U.S., Japan and Germany— because they cover most of the mother patents. Second, our broader set of countries shows how countries that do not host major inventive industries benefit from knowledge transfers through international cooperation. In addition, however, we observe that these transfers flow around the world in anticipation not only of local but also international signals. Knowledge transfers *through* international markets are very likely to happen if opportunities for new markets open up soon.

Whether or not the additional transfer of knowledge within signatory countries as a result of the SO_2 protocols also had an impact on emission reductions cannot be concluded from our analysis. Our data only show that IEAs, or at least the expectation that an IEA will come into existence, induce inventive activities and the transfer of knowledge. Accordingly, the benefit from protocols seems to be the international diffusion of new knowledge in the first place. This is not only in the interest of the countries that lack innovative firms, but also in the interest of these innovative firms themselves (and their host countries).

References

[1] Acemoglu, D. (2001), "Directed Technological Change", Review of Economic Studies 69: 781-809.

[2] Acemoglu, D. and J. Linn (2004), "Market Size in Innovation: Theory and Evidence from the Pharmaceutical Industry", Quarterly Journal of Economics 119(3): 1049-1090.

[3] Acemoglu, D., P. Aghion, L. Bursztyn en D. Hemous (2009), "The environment and directed technical change", NBER Working Paper 15451, Boston

[4] Ackerman, B. and W. Hassler (1981), Clean Coal/Dirty Air, Yale University Press, New Haven.

[5] Albin, C. (2001), Justice and Fairness in International Negotiation, Cambridge University Press, Cambridge UK.

[6] Barrett, S. (2003), Environment and Statecraft: The Strategy of Environmental-Treaty Making, Oxford University Press, Oxford UK.

[7] Eaton, J. and S. Kortum (1999), "International Technology Diffusion: Theory and Measurement", International Economic Review 40: 537-570.

[8] Eaton, J. and S. Kortum and J. Lerner (2004), "International Patenting and the European Patent Office: A Quantitative Assessment", in OECD, Patents, Innovation, and Economic Performance, Paris, 2004, 27-52.

[9] Finus, M. and S. Tjøtta (2003), "The Oslo Agreement on Sulfur Reduction in Europe: The Great Leap Forward?", Journal of Public Economics 87: 2031-2048.

[10] Harhoff, D., F. Scherer and K. Vopel (2003): "Citations, Family Size, Opposition and the Value of Patent Rights", Research Policy 32: 1343-1363.

[11] Hausman, J., B.H. Hall and Z. Griliches (1984), "Econometric Models for Count Data with an Application to the Patents-R&D Relationship" Econometrica 52(4): 909-938.

[12] Imura, H. (2005), "Evaluating Japan's Environmental Policy Performance", in H. Imura and M.A. Schreurs (eds.), Environmental Policy in Japan. Cheltenham, Edward Elgar Publishing, 342-359.

[13] Jaffe, A.B. and M. Trajtenberg (2002), Patents, Citations and Innovations: A Window on the Knowledge Economy, The MIT Press, Cambridge MA.

[14] Joskow, P.L., R. Schmalensee and E.M. Bailey (1998), "The Market for Sulfur Dioxide Emissions", American Economic Review 88(4): 669-685.

[15] Keller, W. (2004), "International Technology Diffusion", Journal of Economic Literature 42: 752-782.

[16] Lanjouw, J.O. and A. Mody (1996), "Innovation and the International Diffusion of Environmentally Responsive Technology", Research Policy 25: 549-571.

[17] Lanjouw, J.O. and M. Schankerman (2004), "Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators", Economic Journal 114: 441-465.

[18] Levy, M.A. (1993), "European Acid Rain: The Power of Tote-Board Diplomacy", in P.M. Hass, R.O. Keohane and M.A. Levy (eds.), Institutions for the Earth: Sources of Effective International Environmental Protection. Cambridge, MIT Press, 75-132.

[19] Murdoch, J.C. and T. Sandler (1997a), "The Voluntary Provision of a Pure Public Good: The Case of Reduced CFC Emissions and the Montreal Protocol", Journal of Public Economics 63: 331-349.

[20] Murdoch, J.C. and T. Sandler (1997b), "Voluntary Cutbacks and Pretreaty Behavior: The Helsinki Protocol and Sulfur Emissions", Public Finance Review 25: 139-162.

[21] Murdoch, J.C., T. Sandler and W.P.M. Vijverberg (2003), "The Participation Decision versus the Level of Participation in an Environmental Treaty: A Spatial Probit Analysis", Journal of Public Economics 87: 337-362.

[22] Placet, M., L.D. Kenkeremath, D.G. Streets, G.E. Dials, D.M. Kern, J.L. Nehring, and C.B, Szpunar (1988), "Markets for Small-Scale, Advanced Coal-Combustion Technologies: A Screening Analysis of OECD Countries", International Coal and Environmental Studies, Argonne.

[23] Popp, D. (2002), "Induced innovation and energy prices", American Economic Review, 92, pp. 160 180

[24] Popp, D. (2006), "International Innovation and Diffusion of Air Pollution Control Technologies: The effects of NO_X and SO_2 Regulation in the U.S., Japan and Germany", Journal of Environmental Economics and Management 51: 46-71.

[25] Sliggers, J. and W. Kakebeeke (eds) (2004), "Clearing the Air, United Nations - 25 years of the Convention on Long-range Transboundary Air Pollution", (United Nations), New York and Geneva.

[26] Sloss, L.L. (2003), Trends in Emission Standards, IEA Coal Research, London.

[27] Vernon, J.L. (1988), Emission Standards for Coal-Fired Plants: Air Pollutant Control Policies, IEA Coal Research, London.

[28] Wooldridge, J.M. (2002), Econometric Analysis of Cross-Section and Panel Data, The MIT Press, Cambridge MA.

Appendix A SO$_2$ protocols and local regulation

Table A.1 summarizes the countries' emission reduction commitments under the Helsinki and Oslo protocols, as well as the year of ratification. Countries without any form of commitment under Helsinki were Japan, United States, United Kingdom and Poland. The latter two committed to emissions reduction under the Oslo protocol up to 50% and 37%, respectively. Whereas the Helsinki protocol implied a uniform emission reduction of 30 percent, the Oslo protocol allowed for differentiated reduction targets. Germany committed itself to the biggest reduction (83%). Other countries with relatively high commitment levels under the Oslo protocol are Austria and the Scandinavian countries Denmark, Finland, Sweden (all 80%), closely followed by the Netherlands (77%) and France (74%).

Table A.1: International SO2 emission reduction cooperation

	1985 Helsinki Protocol		1994 Oslo Protocol	
	Ratification	Commitment$^{a)}$	Ratification	Commitment$^{b)}$
Austria	1987	-30%	1998	-80%
Canada	1985	-30%	1997	-30%
Denmark	1986	-30%	1997*	-80%
Finland	1986	-30%	1998**	-80%
France	1986*	-30%	1997*	-74%
Germany	1987	-30%	1998	-83%
Italy	1990	-30%	1998	-65%
Japan	No	No	No	No
Luxemburg	1987	-30%	1996	-58%
Netherlands	1986**	-30%	1995**	-77%
Poland	No	No	No***	-37%
Sweden	1986	-30%	1995	-80%
Switzerland	1987	-30%	1998	-52%
United Kingdom	No	No	1996	-50%
U.S.	No	No	No	No

$^{a)}$ Uniform 30% emission reduction targets from 1980 SO$_X$ levels by 1993

$^{b)}$ Differentiated emission reduction targets from 1980 SO$_X$ levels by 2000

* No ratification, but approval; ** No ratification, but acceptance;

*** Signing but no ratification (yet)

Source: UNECE (http://www.unece.org/env/lrtap/)

For each country a systematic overview of the various local policies is given below. Data have been obtained from Placet et al. (1988), Vernon (1988) and Sloss (2003). All measures are in mg/Nm3, except noted otherwise. The various regulations were mainly targeted at power plants. Regulatory data for Germany, Japan and the U.S. are checked with Popp (2006). For additional regulatory information on these latter countries see also appendix A of his study.

- Austria
  - 1986: 3000 for 50-100MW; 2000 for 100-200MW; 90% desulf. for >200MW
  - 1987: 400 for >400 M
  - 1989: 400 for lignite >10MW; 400 for hard coal 10-50MW; 200 for >50MW
- Canada
  - 1986: 740 for all new boilers
- Denmark
  - 1986: 860 for >100MW new
  - 1987: 860 for >50MW new
  - 1990: 700 for >100MW new
  - 1991: 400 for new utilities >500MW/therm
- Finland
  - 1987: 600 for 50-150MW new; 370 for >150MW new; 600 for >200MW existing
  - 1988: 400 for >150 MW new
- France
  - 1986: 72% of sulfur in coal
  - 1988: 683 for Paris
- Germany
  - 1983: 400 for new plants; 2000 for existing plants
  - 1993: 400 for existing plants

- Italy
  - 1986: no statutory limits
  - 1987: 1200 for >100MW; 400 after 2-3 years
  - 1990: 1200 for 100-500MW; 400 for >500MW
  - 1991: sliding scale 1700-400 for 100-500MW
  - 2000: 2000 for 50 – 100MW; sliding scale 2000-400 for 100-500MW
- Japan
  - 1968: SO_2 regulations vary by plant according to formula[29]
- Netherlands
  - 1986: 700 for <300MW new and existing; 400 for >300MW new
  - 1991: 200 for >300MW new
  - 1992: 700 for <300MW existing
  - 1994: 400/200 for >300MW existing
- Sweden
  - 1986: 572-972 for plants emitting <800 tons sulfur; 286-572 for plants emitt >800 tons sulfur
  - 1987: 100-170 gram sulfur/GJ fuel input average for plants emitting <400 tons sulfur/year; 50-100 g sulfur/GJ fuel input average for plants emitting >400 tons sulfur/year
  - 1990: 190 gram sulfur/GJ fuel input yearly average for existing plant; 50 g sulfur/GJ fuel input yearly average for new plants
  - 1995: 30 gram sulfur/GJ fuel input yearly average for plant >500MW
- Switzerland
  - 1986: 2000 for all
  - 1987: 2000 for 1-300MW; 400 for > 300MW
  - 1995: 2000 for 1-100MW; 400 for > 100MW
- United Kingdom
  - 1991: 2000 for 50-100MW; 400 for >500MW

[29] Based on region's environmental quality and plant's effective stack height. See p.A3 of appendix in Popp (2006) for an overview of Japanese air pollution regulations.

- United States
  - 1970: Passage of 1970 Clean Air Act setting 1480 for new plants
  - 1977: Passage of 1977 CAA setting 1480 plus an additional 90% SO_2 removal for new plants
  - 1990: Passage of 1990 CAA setting goals for reducing SO_2 emissions through permit trading in two phases applied to power plants[30]
  - 1995: Phase I emissions trading, covering the 263 dirtiest, large generating existing power plants in the country
  - 2000: Phase II emissions trading, covering virtually all (new as well as existing) power plants in the country

[30] See, for instance, Joskow et al. (1998).

Appendix B Patent data description

We use patent data obtained from the European Patent Office (EPO), based in The Hague, the Netherlands. The EPO identifies patents around the world by using both the International Patent Classification (IPC) and the more detailed European Classification System (ECLA). EPO's database can be accessed in different ways. The common approach is to use the online database *esp@cenet*.[31] This classification scheme has a nested structure and allows for searches for specific technologies, such as sulfur dioxide abatement technologies. Also Popp (2006) follows this procedure as explained in his detailed Appendix. Given the search outcomes, some individual patent documents are subsequently screened to tally frequently occurring ECLA classes, where the classes were assessed on their relevance for pollution control technologies (see p.B2 of appendix Popp, 2006). In this way Popp obtains four classes that he considers representative for sulfur dioxide control technologies: B01D53/14H8, B01D53/50, B01D53/86B4 and F23C10. For instance, class B01D53/50 refers to the class of performing operations that aim at separation of gases or vapors, in particular those that purify waste gases, and specifically those targeted at the removal of defined structure like sulfur compounds.

In constructing our patent data set we followed a different approach. In close cooperation with EPO experts we also first constructed a base set by means of keywords but now in order to identify all relevant *individual* patents, not classes. So we fed the entire *esp@cenet* database with keywords. We first used general keywords (step 1) and then imposed combined group-related keywords (step 2). Step 1 and step 2 yielded a set of potentially relevant patents, which were then screened individually on the basis of patent abstracts (step 3) to determine whether the patent was explicitly related to SO_2 abatement or not. If not, the patent was eliminated from the set; it remained in the set otherwise. This third step in the patent retrieval procedure is a distinctive feature of our database. The final step in the procedure (step 4) implied the search for so-called "family members" of each patent in the clean set as obtained through the screening in step 3. Patents are family members if they are based upon the same priority document(s), which means that these are patents that comprise exactly the same claim. This information is particularly relevant because of our focus on international technology diffusion. In the final step 5, we checked the overall set for a language bias. That is, in evaluating the patent abstracts we sometimes encountered patents that were described in a national language, for instance in French or German. We now discuss each step in more detail.

Step 1: Confining the base set by general keywords
We first constructed a base set by using general keywords. Since the focal point of our analysis is sulfur abatement technologies, the search in EPO's database was first restricted to the use of the following combination of keywords: SO_2 or SO_x or +SULFUR+ or +SULPHUR+. A "+" put in front of or after a keyword guarantees

[31] http://www.espacenet.com/

that the search engine yields patents that also contain these original words. For example, "+sulfur+" also yields patents that include the word "desulfurization". The result is a base set that identifies all those patents related to "sulfur". At the date of the first search (26 September 2003), the generated base set contained a total number of 121,913 patents.

Step 2: Restricting the base set by technology-specific keywords
As the next step, we further restricted the patent set to SO_2 abatement technology categories. One well-known technique with a long history in SO_2 reduction is scrubbing, which is typically an of end-of-pipe technology. This category is representative for much of the technologies patented in the 1970s and 1980s. However, scrubbing is not the only technique to deal with SO_2 emissions. Given the range of technical options, we followed the technological distinctions that are included in the RAINS model, developed at the International Institute for Applied Systems Analysis (see http://www.iiasa.ac.at/). The RAINS model classifies the following SO_2 abatement categories (Cofala and Syri, 1998):

1. The use of low-sulfur fuels, including fuel desulfurization;
2. In-furnace control of SO_2 emissions (e.g., through limestone injection or with several types of fluidized bed combustion);
3. Conventional wet flue gas desulfurization processes;
4. Advanced, high efficiency methods for capturing sulfur from flue gas;
5. Measures to control process emissions.

We used this subclassification to define new keywords for subsearches within our initial set of patents. In particular, we used the group-related keywords represented in Table A2. The first subsearch was based on the use of low-sulfur fuels, including fuel desulfurization. The keywords applied for this class are: FUEL, DESULP and DESULF. Subsearch 2 focused on in-furnace control of SO_2 emissions by imposing the keywords COMBUST, BURN, INCINER, LIME, LIMESTONE, CA and CALCIUM. In subsearch 3 we combined classes 3 and 4 of the RAINS classification by simultaneously employing the keywords FLUE and GAS. Note that category 5, with measures to control process emissions, may comprise various techniques. Therefore, we did not specify this class in detail but used expert opinion from the Eindhoven University of Technology, The Netherlands, on relevant characteristics of the newest technologies instead. In this respect, oxidative desulfurization was recognized as a relatively new process to cut back SO_2 emissions. We included "oxidative desulfurization" by using the keywords OXIDATIVE and DESUL in subsearch 4. The subsearches of step 2 reduced the set of potentially relevant patents to 4,243.

Step 3: Individual patent screening

Table A.2: Keywords (in caps) in subsearches

Subsearch	Keywords
1	FUEL and DESULF+ or DESULP+
2	COMBUST or BURN+ or INCINER+ and LIME or LIMESTONE or CA or CALCIUM
3	FLUE and GAS
4	OXIDATIVE+ and DESUL+

The four subsearches outlined above led to a pool of potentially relevant patents. In step 3 all these 4,243 patents were individually screened in order to assess the explicit relationship to SO_2 abatement. If no relationship was found, the patent was removed from the set. It remained in the set otherwise. The total number of rejected patents, including double counts, was 1,741 (41%). Thus, the adjusted patent yield was 2,502.

Step 4: Retrieval of patent families
The final step in the data acquisition procedure required the identification and retrieval of the mother patents and their family members using the clean set of 2,502 patents as obtained in the previous step. Information on the filing procedure is required for labeling a patent as a mother patent or as family member.

The patent office at which a patent is filed assigns an application number and an application date (filing date) to the patent. The application number is unique for each patent filed. The inventor must request a 'novelty search', which is conducted by experts at the patent office. During this search process the experts examine the national patent database and go through international literature to identify the current state of the specific technology (i.e. previous claims that have been made and patents that have been filed).[32] The findings are summarized in a report, after which the inventor may rewrite the application within a given time frame. Essential is that on the basis of the 'novelty search', the actual novelty of the claim made by the inventor is identified. The novelty of the claim is therefore intrinsically linked to the application number. If the technology uses existing knowledge from other patent applications or publications, as identified by the novelty search, these are registered in the patent through patent citations.

Once an inventor files its patent application for the first time (the application date) in a certain country, it has a maximum of one year to also file the same application in other countries. This is the so-called priority year. Important is that the application date in the country of first filing serves as the reference date (priority date) for the novelty search in the additional countries. Only technological developments prior to this date are considered while examining the patent application. In order to make use of this priority right, the inventor needs to add the application number of the initial filing to the list of priority documents (or numbers). This list contains references to previous patent applications done by the inventor over the

[32] For European and international patents a global search in patent databases is required.

same technology. By linking the current application to previous patent applications the list of priority documents provides information on how the technology developed over time and space. If the protected technology is completely new the list of priority numbers only contains the application number.[33]

Formally, we have identified the mother patent as the patent for which the application number and date are equivalent to the priority number and date. Since the filing of a family member is a request for protection of the technology in another country, it also receives a unique application number and application date in that country. The protected technology, however, is exactly the same as the mother patent. Therefore the same list of priority numbers is assigned to the family member as to the mother patent. Family members can thus be defined as patents that have exactly the same priority number(s) as the mother patent, but which are filed in another country and therefore have a different application number. Hereby we follow the definition of the European Patent Office (EPO).

The priority and application numbers of the 2,502 clean patents served as the basis to identify the mother and family patents. Using the priority numbers, a search in EPO's online database *esp@cenet* identified 2,271 mother patents filed between 1970 and 2000. As explained above, multiple patents can be found by entering a priority number due to the existence of family patents and technological improvements over time. If additional priority numbers were encountered during this search process, they were added to the search procedure. To maintain the cleanness of the database all patents were again tested on relevance by screening the patent text based on the keywords mentioned in Table A.2.

Step 4a: European patents and World patents

European patents (EP) and international patents (WO) are special patents, because each such patent grants protection in multiple countries. The inventor can opt to file a European or international patent application in one patent office instead of filing several patents at the national offices of those countries. The inventor can choose in which participating countries of the patent treaties (European Patent Convention or the Patent Cooperation Treaty) patent protection is requested. If during our search a European or international patent was encountered, the countries in which protection was requested were registered using the official document (in pdf-format). If the new technology was directly filed as a European or international patent, the priority document(s) therefore include the EP#### or WO#### reference. The mother country was identified by means of this official document in which the filing office was mentioned. If the filing office was lacking, the mother patent was assigned to the country of origin of the inventor. The countries mentioned in the document, excluding the mother country, were identified as countries holding a family member. If the new technology was first filed at a national patent office

[33] Note that the list of priority numbers is different from a patent citing, which refers to a previously filed patent from which (some of) the essentials are used in a new, but potentially different, type of technology. Hence the former refers to the development of a single technology, while the latter refers to knowledge spillovers in general.

and then internationally protected by means of European and international patents, the mother patents were assigned to a country on the basis of the priority number, i.e., DE#### belonged to Germany, U.S.#### to the U.S., etcetera. During the 1970-1997 period, 287 EPs and 97 WOs were filed respectively.

Example In the following case the European patent serves both as mother patent and as family member.

- Priority #: EP19970114906 - priority date: 28 August 1997
- Mother patent: EP0899001 - filed by a German inventor at the European Patent Office. Therefore it is assigned to Germany.

Besides the national family members in the U.S., Japan and Canada, the original document shows that additional protection is requested in Austria, Switzerland, Denmark, Finland, France, UK, Italy, Luxemburg, Netherlands, Sweden and more European countries. In the next case the European patent serves only as family member.

- Priority #: DE19782839541 - priority date: 12 September 1978
- Mother patent: DE2839541 - Germany
- European patent: EP0008770 - filed on 29 August 1979, entails Belgium, Switzerland, France, UK, Luxemburg, Netherlands and Sweden as a family member.

If the mother country is also included in the pdf it is not registered to prevent double counting. Other family members are JP55039298 and DK150704.

For certain European and international patents the family members showed an overlap for the countries in which the technology was protected with patents filed at national offices. For instance, if an EP patent was part of the WO patent or the EP patent had a national equivalent. To prevent double counting we have ranked the family members in the order from national to international patent. Thus if there was already a national family member it was not registered anymore as part of the EP and/or WO patent. The countries protected by the EP patent were not listed anymore as part of the WO patent.

Once a WO patent is filed all nationally registered family members receive the application number (WO####) of the international patent as additional priority number. Due to the strict definition of patent families these family members should be treated as members of a different (new) family for which no mother patent exists, as illustrated by the following example.

Example

- Priority #: DE19971053191 - priority date: 21 November 1997
- Mother patent: DE19753191 - Germany
- Family members: PL340564, WO9926713, EP1039964 and AU751684B

The Australian patent (AU751684B) is discarded because is does not belong to the countries researched. All three other family members are filed on 18 November 1997. For the Polish (PL340564) and EP patent (EP1039964) one can see the added WO1998EP07368 in the priority number row. In addition, this example illustrates the issue of double counting. By looking at the original document of the international patent, we can see that it offers protection in multiple countries. One of these countries is Poland, which is already registered by the national patent. Furthermore, a reference is made to the EP patent, which was also already registered. To prevent double counting we have not registered these patents again as family members. For this particular WO patent it turned out, that it did not provide us with additional family members within our group of countries.

A final remark on the registration of patent family members concerns the registration of Canadian patents. The online database *esp@cenet* had some trouble in retrieving the priority and filing documents of Canadian patents and represented them as CAD000000.[34] To obtain the correct information for these patents, we have used the database of the Canadian Intellectual Property Office and the information from family members. By searching for the specific patent numbers, which were correctly reported in *esp@cenet*, the required information was obtained.

Step 5: Testing for language bias

In evaluating the individual patent abstracts we sometimes encountered patents (title and/or abstract) that were described in a national language, for instance in French or in German. In most cases an English abstract was available as well, but not for all. This brought up the issue of a potential language bias in our database. In order to check for this language bias, and to identify the relevance of these patents, we translated the keywords. Table A.2 contains the used keywords in the respective languages.

Within *esp@cenet* it is possible to search within a limited number of national databases and within the worldwide database. The worldwide database includes patents from over 70 countries and regions and also covers the publications from the national databases. Within the national databases one can search using national languages, while in the worldwide database only the English language is allowed. To retrieve patents written in a national language from the worldwide database English keywords are sufficient according to the *esp@cenet* help file. Although titles are indexed with English keywords, there still may be some patents that have abstracts written in another language, such as German.

[34] See http://v3.espacenet.com/textdoc?DB=EPODOC&IDX=CA1022728&F=0&QPN=CA1022728 for an example.

Table A.3: Keywords in different languages

English	**German**	**French**	**Dutch**
SO_2	SO_2	SO_2	SO_2
SO_x	SO_x	SO_x	SO_x
Sulfur/sulphur	Schwefel	Soufre	Zwavel
Fuel	Brennstoff, brandstoff, benzin	Combustible	Brandstof
Combust	(ver)brennbar	Combustible	Brandbaar
Lime	Kalk	Platre, Mortier	Kalk/calcium
Gas	Vergasen	Gaz, gazifier	Vergassen
Oxidation	Oxydation	Oxydation	Oxidatie
Flue	Schornstein, Abzurgsrohr	Carneau	Schoorsteen, rookkanaal
Desulfurization	Entschwefelung		Ontzwaveling

To test for a language bias, we used different translations of the word 'sulfur'. Using the German translation of sulfur into the worldwide database provides zero hits. The Dutch translation also generates zero hits, since the patents filed in the national database can be retrieved in the worldwide database having English titles and/or abstracts. Only one French patent from 1903 was found by using "soufre" as a keyword. However, 54 Canadian patents were retrieved by this search of which 24 also have English abstracts and family members. None of them passed the selection criteria described in step 2. Out of the 54 Canadian patents 12 were filed outside of the period covered by this research. For the remaining 18 patents *esp@cenet* did not provide the priority number and date (see step 4; CAD000000). As a final remark regarding the testing of the language bias, note that the power of the search engine used by *esp@cenet* is smaller than the one used by the patent experts of EPO. For instance, it does not allow for subsearches as described in step 2.

Help-files on the sites of the Canadian Intellectual Property Office and *esp@cenet* make clear that for most Canadian patents granted before 15 August 1978 abstracts and claims were unavailable.[35] For this reason priority dates and numbers cannot be retrieved in the *esp@cenet* database and we might have missed several patents filed in French. The 18 remaining patents were all granted between 1970 and 1978 and were filed only in French. Language barriers and the absense of an abstract prevent a full screening of those patents and we therefore exclude them from the database. Despite this potential language bias we decided to maintain the other Canadian observations for this period within our database. First, the Canadian family members from this period were detected by our described search process in

[35]The text of the abstracts and claims is not available for patents that were granted prior to August 15, 1978. These patents can only be searched by their patent number, titles, owner or inventor names, or classification. Canadian patent applications can be filed in either English or French. All patent documents on this site have both English and French titles. However, between 1960 and 1978, titles are available only in the language used at the time of filing. http://patents1.ic.gc.ca/content-e.html. Abstracts where published systematically from 1978 onwards, although there are some earlier Abstracts, if provided by the applicant, mostly in English. http://patentinfo.european-patent-office.org/_resources/data/pdf/canada.pdf

esp@cenet. Second, the fact that the referred period falls outside of the influence of the protocols, the limited share of Canada in the number of patent filings and the small language bias for other countries provide enough confidence in the quality of our database.

Appendix C Data sources and definitions of variables

- *MOTHER AND FAMILY PATENTS:* See Appendix B for a detailed explanation of our counts, including the distinction between EP/WO and national counts. Source: European Patent Office in The Hague, The Netherlands

- *COAL SHARE*: Defined as total production of electricity generated from coal inputs relative to total electricity produced. Source: Energy Balances, Statistical Compendium, ed. 01, CD-ROM, Paris: OECD.

- *TOTAL PATENTS:* Overall number of claimed patents for all types of technologies filed in each country, i.e., all mother patents that have been claimed in at least one other country (so having at least one family member). Source: OECD

- *RESEARCH*: Gross Domestic Expenditures on R&D as a percentage of GDP. For explanation of R&D epxenditures see http://www.uis.unesco.org/ev.php?ID=5127_201&
Source: Main Science and Technology Indicators OECD

- *EVENT DUMMY* Own construction with dummy equal to 1 if country is signatory country of a specific protocol. See table 3 in main text.