Invention and Transfer of Environmental Technologies

Chapter 2

Environmental Policy, Multilateral Environmental Agreements and International Markets for Innovation

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Flexibility of the national policy framework and international policy co-ordination are two key factors that affect international transfer of environmental technologies. In this chapter, empirical evidence is provided that indicates that the degree of flexibility of national environmental policy regimes has a positive effect on technology transfer. Flexibility ensures that markets are not fragmented across different countries as would be the case with prescriptive regimes. In the second case, we also examine whether adherence to a series of international agreements on reducing SO_X and NO_X emissions has induced the transfer of technologies between signatory countries. Supporting descriptive and econometric evidence to this end is provided.

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Introduction

International technology transfer (ITT) can provide significant economic benefits, giving countries access to inventions which improve macroeconomic performance (see Keller, 2002; Coe and Helpman, 1995). Based on an extensive review of empirical studies Keller (2002) argues that foreign sources of technology account for 90% of domestic productivity growth. As a consequence, it is important to ensure that appropriate framework conditions are in place in order to encourage the international diffusion of technologies.

While this is true of OECD economies, it is particularly true of non-OECD economies (see *e.g.* Savvides and Zachariadis, 2005; Schiff and Wang, 2008) since the majority of R&D is still undertaken by OECD countries. Helping less-developed economies get on the "first rung of the innovation ladder" is, of course, an important development policy objective of OECD economies. Indeed, Article 66 of the TRIPS Agreement "requires developed countries' governments to provide incentives for their companies to transfer technology to least-developed countries". The extent to which this obligation is implemented in an explicit manner is, however, unclear (see Maskus, 2004). However, it is interesting to note that in a study of regulation of coal-fired electricity generating plants, Lovely and Popp (2008) find that international economic integration eases access to environmentally friendly technologies and leads to earlier adoption of regulation in developing countries.

There is another important motivation for encouraging the international transfer of technologies in which some of benefits arising from these transfers are transnational in nature. Specifically, for technologies whose impacts have international "public good" characteristics, the source country can indirectly benefit from the transfer in various non-market forms. For example, policies that are designed to address issues of *public health* which cross national borders (*i.e.* infectious diseases such as SARS) generate clear benefits in encouraging the transfer of technologies which mitigate these adverse impacts. Indeed, it might be argued such potential "win-wins" were part of the motivation for the WTO "Medicines Decision" (see Abott, 2005).

The case is even stronger with respect to (at least some) *environmental* concerns. For the technology source country, the welfare implications of the transfer of technologies to recipient countries which mitigate trans-frontier (*e.g.* regional pollutants such as sulphur dioxide) or global "public bads" (*e.g.* greenhouse gas emissions such as carbon dioxide) are very different than the transfer of technologies in which such impacts are absent. More specifically, in the case of global public "bads", all countries (including the source country) benefit from increased greenhouse gas mitigation, irrespective of its location.

It is precisely for this reason, of course, that a number of Multilateral Environmental Agreements (MEAs) have included elements which encourage ITT. Examples include the Multilateral Fund for Implementation of the Montreal Protocol as well as Annex III-Article 5 of the United Nations Convention on the Law of the Sea. The effectiveness of these different measures varies, with the Multilateral Fund standing out as being a particular success story.

In the context of climate change, a Special Climate Change Fund was initially created under the Marrakech Accords. At COP 16 in Cancun richer countries promised to provide USD 100 billion by 2020 for a "Green Climate Fund" to help developing countries finance investment in clean energy technology. In addition, a Technology Executive Committee was established to analyse "needs and policies for transfer to developing countries of technology for clean energy and adaptation to climate change". Recent work on the Clean Development Mechanism also supports the hypothesis that the CDM can be an important source of both "embodied" and "disembodied" technology transfer (see Dechezleprêtre *et al.*, 2008; Seres *et al.*, 2010; Haščič and Johnstone, 2011).

However, the domestic policy framework can also play a role in encouraging ITT for environmental inventions. Unlike many other areas, "demand" for environmental inventions is largely driven by the public policy framework (for evidence see Lanjouw and Mody, 1996; Brunnermeier and Cohen, 2003; Johnstone *et al.*, 2010). As a consequence, the relative degree of stringency and other design characteristics related to domestic environmental policy can have implications for the international diffusion of technologies. Conversely, incompatible domestic policy frameworks may create barriers for international transfer.

Drawing on a database of patent applications from a wide cross section of countries, this paper provides evidence for the positive effect of "flexibility" of the domestic environmental policy regime on the propensity for the inventions induced to be diffused widely in the world economy. In addition, the role that multilateral environmental agreements (MEAs) can play in encouraging technology transfer is examined. In order to undertake these analyses, a measure of international technology transfer is developed for environmental technologies. This measure is then used to examine the role of both the domestic policy framework and MEA's in encouraging transfer. The results of the empirical analyses confirm the positive role of policy flexibility and international co-operation on technology transfer.

International transfer of environmental technologies

Overall, our understanding of patterns of technology transfer remains limited. Through the use of citation data, a small number of papers (Peri, 2005; Co, 2002; Maurseth and Verspagen, 2002) have extended the insights obtained from gravity trade models to examine trade in knowledge. In one of the few papers to model the international diffusion of technologies (and not ideas and knowledge), Eaton and Kortum (1996) modelled the probability that a claim for a patented invention originating in a particular country would be filed in another country. Amongst the determinants they included geographic distance between the countries and the level of trade between the countries, as well as the level of human capital in the "adopting" country. They find that diffusion falls rapidly with geographic distance.

Technology transfer can be either embodied or disembodied, and take place through the market or by non-market means. A possible taxonomy might take the following form (see Maskus, 2004; Hoekman and Javorcik, 2006):

- Market:
  - Trade in goods and services.

  - Foreign direct investment.
  - Licensing.
  - Joint ventures.
  - Cross-border movement of personnel.
- Non-market:
  - Imitation and reverse engineering.
  - Employee turnover.
  - Published information (journals, test data, patent applications).

The empirical evidence strongly supports the finding that the bulk of technology transfer takes place via trade, foreign direct investment and licensing (Maskus, 2004). Precisely which channel is most important depends in part on the characteristics of the "recipient country" (domestic research capacity, strength of intellectual property rights regimes, etc.) and nature of the technology being "transferred" (*i.e.* potential for imitation and reverse engineering). The use of patent data to measure international technology transfer arises from the fact that there will be a partial "trace" of all three of these channels of transfer in patent applications. If there is any potential for reverse engineering, then exporters, investors, and licensors have an incentive to protect their intellectual property when it goes overseas.

The potential to use patent data as the base from which to develop a proxy measure of technology transfer arises from the fact that protection for a single invention may be sought in a number of countries. While the vast majority of inventions are only patented in one country (often that of the inventor, particularly for large countries), some are patented in multiple countries (*i.e.* the "international patent family size" is greater than one). Such "duplicate" applications can then be used to develop indicators of technology transfer. Of course, a patent only gives the patentee protection from potential imitators. It does not reflect actual transfer of technologies. If applying for protection did not cost anything, inventors might patent widely and indiscriminately, and duplicate patent applications would not be a good proxy variable for transfer.

However, patenting is costly – both in terms of the costs of preparation of the application and in terms of the administrative costs and fees associated with the approval procedure (see Helfgott 1993 for some comparative data; Berger (2005) and Van Pottelsberghe and François (2006) also provide more recent data for European Patent Office applications). Moreover, if enforcement is weak, the publication of the patent in a local language can increase vulnerability to imitation (see Eaton and Kortum, 1996, 1999). Independently, inventors are unlikely to apply for patent protection in a second country unless they are relatively certain of the potential market for the technology that the patent covers (see the Annex A to this volume for methodological discussion and empirical evidence on the reliability of such a measure).

In this paper, indicators of transfer were developed for technologies that relate to air pollution abatement, water and wastewater treatment, and solid waste management. The patent classes are the same as those used in the previous chapter, and are listed in Annex B. (For more information see *www.oecd.org/environment/innovation/indicator*.) The data was extracted from the *EPO Worldwide Patent Statistical (PATSTAT) Database*, and measures of transfer were developed, with priority office defined as the "source" country and duplicate office as the "host" country. Figure 2.1 presents the most important bilateral

Figure 2.1. **International transfer of selected environmental technologies (1975-06)**

A. Air

B. Water

C. Waste

Note: This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

transfer relationships for air pollution abatement, water and wastewater treatment, and solid waste management, based on patent applications filed from 1975 to 2006.

However, the extent of transfer of "environmental" technologies is partly a consequence of close economic relations more generally. In Table 2.1 the data is normalised by total rates of transfer, and the most "environment-intensive" flows are presented. For example, almost 19% of all technologies transferred from Japan to Poland relate to "environmental" technologies.

Table 2.1. **Most AWW-intensive bilateral transfer relations (2001-03)**

Source	Recipient	AWW transfer	Total transfer	Share (%)
JP	PL	36	191	18.85
NL	BE	7	61	11.48
CZ	SK	8	76	10.53
AT	MX	8	90	8.89
CN	HK	10	122	8.20
AT	PL	9	114	7.89
NO	MX	5	64	7.81
FI	MX	11	142	7.75
PL	AU	15	212	7.08
CZ	AU	6	85	7.06
RU	UA	8	115	6.96
FI	NO	18	259	6.95
JP	ZA	17	246	6.91
FI	PL	9	132	6.82
KR	SG	4	60	6.67
GR	AU	6	92	6.52
CA	NZ	4	62	6.45
UA	RU	19	299	6.35
GB	IE	6	97	6.19
AU	NZ	46	761	6.04
CA	KR	5	83	6.02
AT	BR	11	183	6.01

Note: Number of duplicate patent filings in AWW-relevant fields as a share of overall transfer, 2001 to 2003. "Environmental" technologies covered include: Air + Water + Waste, or AWW. Only bilateral relations with total transfers greater than fifty applications were included.

The role that domestic policy factors and multilateral environmental agreements play in encouraging inventors to protect their inventions in multiple countries is the subject of the following two sections.

Environmental regulation and fragmentation of innovation markets

While the empirical evidence on the effects of environmental policy on trade in goods and services remains limited and ambiguous (see Levinson and Taylor, 2008 for new results and a methodological discussion of the reasons why positive evidence in this area remains limited), there is reason to expect that differences in environmental policy regimes would have an effect on international trade and foreign direct investment patterns. Indeed some environmentalists have argued that the stringency of environmental policies should be harmonised in order to avoid such effects, but this is unlikely to be welfare-improving.

Environmental policies may differ across countries due to both supply (*i.e.* ecological conditions) and demand (*i.e.* preferences for environmental quality) conditions, and these factors should be reflected in domestic policy regimes if it is to bring about welfare improvements. While there are some arguments for policy harmonisation in certain cases (*e.g.* imperfect enforcement, trans-frontier pollution), economists are more concerned with the potential for domestic environmental policy to be used as a barrier to trade in order to protect domestic industries (see Ederington and Minier, 2003 for an empirical study) (see Greaker and Eggert, 2008 for a discussion of the GMO case).

Unfortunately, much of the relevant literature in this area has focused on the effects of differences in the stringency of environmental policy, and not on the effects of differences in policy design. In addition to their effects on the *rate* of innovation, different policy measures (of equal stringency) are likely to generate different *types* of innovation. As such, if different countries introduce different types of policy measures, there is likely to be national specialisation in different types of technological innovation to meet similar environmental objectives. This fragmentation of environment-related innovation along national lines can result in increased costs in meeting given environmental objectives. While the effects of policy design on the international diffusion of innovations has not been addressed in the literature, in other areas there is evidence of the costs associated with differentiated regulatory systems for pharmaceutical (Vogel, 1998) and food (Thilmany and Barrett, 1997) markets. In the environmental domain there have been a number of studies on the effect of differentiated gasoline content regulations in the United States on gasoline price levels and variability (see Morriss and Stewart, 2006; Chakravorty and Nauges, 2005; Chakravorty *et al.*, 2008).

In addition to the price effects of policy heterogeneity, the potential innovation effects of this regulatory heterogeneity may be considerable. Since investment in R&D is risky, any measures that constrain the potential market for innovations generated are likely to present a significant disincentive. Moreover it can be costly to gather the information required in order to determine what types of innovations are likely to be permitted under a wide variety of policy regimes. However, no empirical evidence on the innovation impacts of policy design is available.

The specific effect of the "flexibility" of domestic environmental policy has not been addressed in the literature. Since flexible environmental policies – whether they are environment-related taxes, tradable permit systems, or even non-prescriptive performance standards – allow for the use of a wide variety of technological measures, the international market opportunities for the technologies thus arising are likely to be wider. It might be imagined that such effects could further be realised through the implementation of identical technology-based standards. Indeed this is similar to the arguments put forth by Sykes (1995) and others.[1] However, this assumes a level of co-ordination that is unlikely to be realised in practice for environmental technologies, although de Coninck *et al.* (2008) provide some examples of international technology-oriented agreements related to climate change.

Alternatively, in circumstances where a dominant country regulates first, the policy may induce innovations that affect the policy decisions of subsequent regulators, encouraging them to adopt similar regulations. The example of California motor vehicle emissions controls might represent such a case (see Vogel, 1995. However, an empirical study by Fredriksson and Millimet, 2002 finds limited evidence of the "California effect" in state-level environmental policy-making). While this may result in an unfragmented market, it does so at the cost of imposing regulations of equal stringency across countries with different ecological conditions and heterogeneous demand for environmental quality. There is no reason to expect that the optimal path of innovation will be induced.

Conversely, the use of flexible instruments allows for both broad markets for innovation as well as differentiated levels of stringency. In effect, with flexible policy instruments the level of stringency determines the size of different national markets, without bringing about market fragmentation.

Data construction

Exploiting the transfer data discussed above, it is possible to examine the role that policy design plays in allowing countries to exploit international technological opportunities. However, given the heterogeneity of environmental policy regimes both across countries, and within countries across sectors and impacts (as well as through time), it is difficult to construct a general index of the "flexibility" of environmental policy regimes. Fortunately, in the period 2001 to 2003, the World Economic Forum's *Executive Opinion Survey* asked respondents a number of questions related to environmental policy design.

The survey is implemented by the WEF's partner institutes in over 100 countries, which include departments of economics in leading universities and research departments of business associations. The means of survey implementation varies by country and includes postal, telephone, Internet, and face-to-face survey. In most years there are responses from between 8 000 and 10 000 firms (see Sala-i-Martin *et al.*, 2008 for a description of the sampling strategy). Specifically, respondents (usually CEOs) were requested to indicate the extent to which they had the freedom to choose different options in order to achieve compliance with environmental regulations. Respondents were requested to assess the degree of flexibility on a Likert scale, with 1 = offer no options for achieving compliance, 7 = are flexible and offer many options for achieving compliance (HSTFLEX and SRCFLEX).

For a given level of flexibility, the stringency of environmental policy will determine the size of markets for innovation. So it may be necessary to control for differences in the stringency of environmental policy across countries and over time. For this purpose an index of perceived stringency of a country's overall environmental regulation is used (Sala-i-Martin *et al.*, 2008). The degree of stringency has been assessed on a Likert scale, with 1 = lax compared with that of most other countries, 7 = among the world's most stringent (HSTSTRNG and SRCSTRNG).

As found in more general studies of technology transfer, domestic absorptive capacity is an important factor. In practice, while the number of scientific personnel or expenditures on R&D in the relevant fields could be used as measures of domestic scientific capacity, the lack of data for many non-OECD countries (even at the macroeconomic level) prohibits the use of such a measure. Therefore, we use patent data to measure absorptive capacity of the recipient country. A count of patented inventions by domestic (*i.e.* recipient country's) inventors is included for this purpose (ABSCAP).

Technologies may only be transferred if they have been developed in the first place. To capture the stock of inventions in a given source country that are potentially available for transfer elsewhere, a variable (AWWSTOCK) is constructed that reflects the number of patent applications by domestic inventors filed in the current year or the three previous years. This time span is appropriate given the limitations on international patenting imposed by international patent treaties.[2] Thus the mode of the distribution of transfer lags is between 1 and 2 years, as expected. It must also be noted that, as in the case above, the entire stock of inventions in PATSTAT is considered when constructing the variable, including inventions for which no claims for protection have been sought in countries other than that of the priority office. The sign of this variable is expected to be positive.

Finally, differences in the general propensity to transfer patents between countries and over time are captured through the use of a variable that reflects overall duplicate patent applications filed across the whole spectrum of technological areas (TOTALTT). This variable should capture all of the more general economic factors that are likely to influence transfer (common language, geographic distance, commercial relations, strength of intellectual property rights, etc.) but that are not specific to "environmental" innovation. The sign is expected to be positive. In other words, while TOTALTT controls for any factors that determine the *rate* of transfer, the remaining explanatory variables measure the role of factors that "bend" the *direction* of this transfer towards more environmental ends. Table 2.2 gives the basic descriptive statistics for the sample used in the model presented below.

Table 2.2. **Descriptive statistics for the panel dataset**

Variable	Observed	Mean	Standard deviation	Minimum	Maximum
$AWWTT_{ijt}$	21 822	0.57	8.27	0	498
$SRCFLEX_{it}$	21 822	3.94	0.62	1.7	5.4
$HSTFLEX_{jt}$	21 822	3.94	0.62	1.7	5.4
$SRCSTRNG_{it}$	21 822	4.12	1.31	1.2	6.7
$HSTSTRNG_{jt}$	21 822	4.12	1.31	1.2	6.7
$AWWSTOCK_{it}$	21 822	421.25	1 273.64	0	7 790
$ABSCAP_{jt}$	21 822	109.32	329.02	0	2 024
$TOTALTT_{ijt}$	21 822	42.74	768.19	0	49 584

The empirical model

Our aim is to analyse the relationship between the nature of policy regimes and technology transfer. To do so, we construct a gravity model that allows us to examine all potential bilateral relations between source and recipient countries. The hypothesis is that, other things being equal, more "flexible" environmental policy regimes are likely to generate innovations with broad potential acceptance in overseas markets. Figure 2.2 provides a scatter plot of the relationship between the index of the flexibility of environmental policy regimes and the log of "exports" (outflows) of environmental technologies (measured by duplicate patent applications), suggesting a positive relationship with the correlation coefficient = 0.45 (at < 0.001% significance level).

Moreover countries with more flexible policy regimes are more likely to be able to benefit from inventions developed elsewhere. As such, Figure 2.3 presents the same information but from the viewpoint of the recipient country. The relationship between the flexibility index and "imports" (inflows) of environmental technologies is positive, with the correlation coefficient = 0.26 (at < 0.001% significance level).

Based on the discussion above, the following model is specified:

$$AWWTT_{ijt} = f\,(SRCFLEX_{it},\ HSTFLEX_{jt},\ SRCSTRNG_{it},\ HSTSTRNG_{jt},\ AWWSTOCK_{it},\ ABSCAP_{jt},\ TOTALTT_{ijt},\ \gamma_i,\ \delta_j,\ \omega_t) + \varepsilon_{ijt}$$

where i represents the source country, j the recipient country,[3] and t = 1998, …, 2006 indexes over time.[4]

Figure 2.2. **Relationship between the flexibility of environmental policy regimes and source country patent applications**

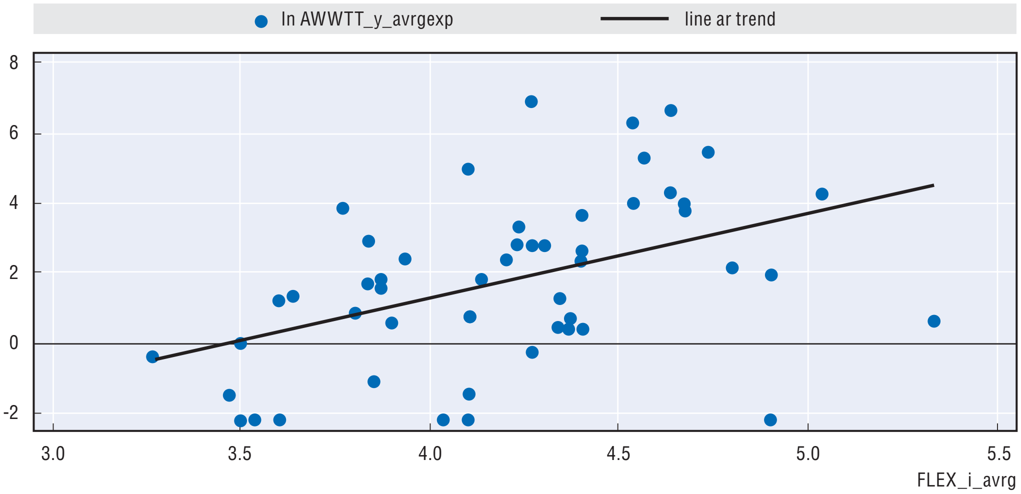
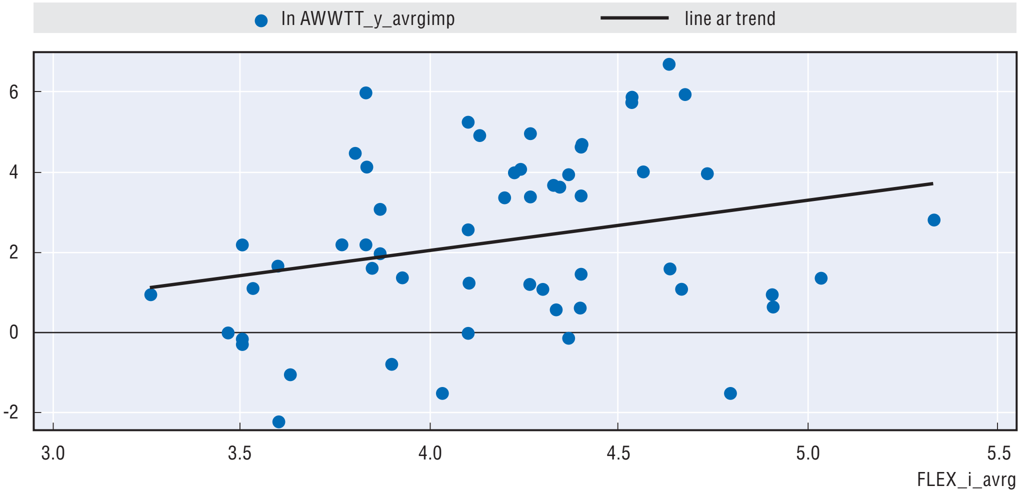


Figure 2.3. **Relationship between the flexibility of environmental policy regimes and patent applications in recipient country**



Our dependent variable is a measure of the number of patents in the source country *i* (the "priority" office) for which protection has also been sought in recipient country *j* (the "duplicate" office) in year *t* (the year of duplication). On the right-hand side of the equation, SRCFLEX_{it} and HSTFLEX_{jt} reflect the degree of flexibility of the source and recipient country's environmental policy regimes, respectively. It is expected that the sign of these variables is positive. Similarly SRCSTRNG_{it} and HSTSTRNG_{jt} reflect the degree of stringency of the source and recipient countries' environmental policy regimes.

AWWSTOCK_{it} is the available stock of inventions in environment-related technologies measured as the sum of patent applications invented in the source country during the current and the previous three years. The sign is expected to be positive. ABSCAP_{jt} is the total number of patent applications for environment-related technologies invented in the recipient country and the expected sign is positive, since increased absorptive capacity should increase transfers. Last, $TOTALTT_{ijt}$ is the total number of patents that is transferred from the source country to the recipient country, and sign is expected to be positive. Fixed effects γ_i, δ_j, ω_t are included to control for any omitted time- and country-specific heterogeneity. All the residual variation is captured by the error term (ε_{ijt}). Given the count nature of the dependent variable, the equation is estimated as a negative binomial model using maximum likelihood (for further details on negative binomial models, see Cameron and Trivedi, 1998).

Results and discussion

Several alternative model specifications are estimated (Table 2.3). This includes models where the flexibility index varies over time, placing a constraint on the length of the panel, 2001-03 (Models 1 and 2). Alternatively, the mean value of the index is used instead allowing for a longer panel, 1998-2006 (Models 3 and 5). However, this is shorter when the stringency variables are included as the data is only available for the 2001-06 period (Models 4 and 6). Finally, in the last two models only observations with non-zero overall transfer were included (TOTALTT > 0). Thus, the sample size varies between 90 900 and 4 946 observations.

Table 2.3. **Estimated coefficients of the AWW technology transfer model**

Dependent variable: $AWWTT_{ijt}$	Using $FLEX_{jt}$ (time-variant)		Using $FLEX_{j\_avg}$ (mean values of the flexibility index)			
	Full sample		Full sample		Sub-sample, if TOTALTT > 0	
	t = 2001-03		1998-2006	2001-06	1998-2006	2001-06
	(1)	(2)	(3)	(4)	(5)	(6)
$SRCFLEX_{it}$	1.5741***	0.4906**	2.2157***	0.6880***	1.2422***	0.5282*
	(0.1299)	(0.1630)	(0.1449)	(0.2009)	(0.1527)	(0.2153)
$HSTFLEX_{jt}$	1.2925***	0.9103***	1.5577***	1.2511***	0.6237***	0.8400***
	(0.1145)	(0.1575)	(0.1141)	(0.2359)	(0.1416)	(0.2504)
$SRCSTRNG_{it}$		0.7329***		0.7127***		0.3482***
		(0.1038)		(0.1070)		(0.0785)
$HSTSTRNG_{jt}$		0.2513**		0.2118		–0.0294
		(0.0894)		(0.1201)		(0.0876)
$AWWSTOCK_{it}$	3.51E-04***	3.13E-04***	4.06E-04***	3.65E-04***	2.27E-04***	2.00E-04***
	(4.56E-05)	(4.62E-05)	(4.45E-05)	(4.41E-05)	(4.03E-05)	(4.15E-05)
$ABSCAP_{jt}$	1.16E-03***	1.18E-03***	1.28E-03***	1.29E-03***	5.40E-04***	4.88E-04***
	(1.23E-04)	(1.26E-04)	(1.05E-04)	(1.10E-04)	(1.05E-04)	(1.08E-04)
$TOTALTT_{ijt}$	3.43E-03***	2.43E-03**	3.44E-03***	2.01E-03**	9.09E-04**	7.80E-04**
	(1.03E-03)	(8.31E-04)	(1.08E-03)	(7.43E-04)	(3.17E-04)	(2.78E-04)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N of obs.	21 822	21 822	90 900	37 200	8 866	4 946
N of country-pairs	10 100	10 100	10 100	10 100	1 832	1 526
Log Pseudolikelohood	–5 644.45	–5 494.47	–15 452.13	–7 784.96	–11 683.28	–6 208.74
Wald chi2	1 453.27	1 422.79	2 377.15	1 713.34	764.86	565.94
(Prob > Chi2)	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for country-pair clusters are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The empirical results confirm all of our principal hypotheses. Starting with the control variables, the results suggest that the stock of inventions that are potentially available for transfer in the source country, as well as the absorptive capacity of the recipient country, are both important determinants of transfers of "environmental" technologies. Moreover such transfer is positively (and significantly) correlated with the volume of technology transfer overall. These results hold for all the alternative models estimated.

When it comes to characterisation of the differences in policy regimes between the source and recipient countries, the results suggest that countries with more flexible policy measures are more likely to be able to "export" their inventions to markets abroad as well as benefit from inventions already developed elsewhere. The estimated coefficients are positive and statistically significant in all models estimated. Moreover controlling for differences in policy stringency (or not) does not affect the qualitative nature of this finding.

We note that the models reported here include year fixed effects. Convergence problems prevented us from including also country fixed effects. However, country-specific heterogeneity is already controlled for by a number of regressors in the model that vary across individual countries.

Table 2.4 presents the elasticities for the models estimated. Overall, the elasticity of transfer of environmental technologies with respect to the four policy variables is much higher than with respect to the other control variables. An interesting result is that, controlling for the effect of stringency (Models 2, 4, 6), the estimated elasticity of transfer with respect to policy flexibility is always higher for host-country than that for source-country. There is some evidence that the converse is true for policy stringency. These results indicate that while stringent and flexible policies are important in both source and recipient countries, on the margin there is a difference in their relative importance. Specifically, our results suggest that if increasing ITT in environmental technologies is the objective then it is relatively more important that stringent policies be implemented in countries that tend to generate innovations (source countries) rather than in countries that tend to rely on imports of such innovations (recipient countries). On the other hand, having flexible (technology-neutral) policies is relatively more important for technology importers than for technology producers.

Table 2.4. **Estimated elasticities**

	(1)	(2)	(3)	(4)	(5)	(6)
$SRCFLEX_{it}$	6.1963***	1.9312**	8.6296***	2.7290***	5.3670***	2.2809*
$HSTFLEX_{jt}$	5.0876***	3.5835***	6.0669***	4.9628***	2.6486***	3.5929***
$SRCSTRNG_{it}$		3.0232***		3.0316***		1.8258***
$HSTSTRNG_{jt}$		1.0366**		0.9011		–0.1476
$AWWSTOCK_{it}$	0.1478***	0.1318***	0.1445***	0.1707***	0.2948***	0.2933***
$ABSCAP_{jt}$	0.1272***	0.1292***	0.1223***	0.1600***	0.1742***	0.1901***
$TOTALTT_{ijt}$	0.1464***	0.1039**	0.0886***	0.0825**	0.2402**	0.2405**

Note: Conditional elasticities evaluated at sample means.

In summary, there appears to be a strong relationship between CEO's perception of the flexibility of environmental policy regimes in different countries and the spatial scope of diffusion of inventions that are patented in these countries. These results provide further support for the use of "flexible" instruments (including market-based instruments) in environmental policy.

Multilateral environmental agreements and technology transfer

While the characteristics of the domestic policy framework appear to have an influence on the propensity for technology transfer (Chapter 3), the international policy framework can also play a role. In particular, and has been noted above (Chapter 1), a number of multilateral environmental agreements encourage sharing of knowledge and technologies. In this section we use a sub-set of the technologies used in the previous section to assess the role of multilateral environmental agreements in encouraging the transfer of abatement equipment that reduces pollutants contributing to acid rain.[5]

Among the most notable effects of acid rain[6] are its negative impacts on surface waters, soil and forest cover. It arises from airborne emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_X). Acid rain has been a political issue for over three decades. Moreover, it has often resulted in international political tensions due to the trans-frontier pattern of its deposition. While considerable reductions of these emissions have been achieved in recent years (Annex 2.A1 provides data on emissions from OECD member countries), emissions remain considerable. Most OECD countries have policies in place with an objective to further reduce emissions. Indeed, a proposed tradable permit scheme in the European Union is under discussion (ENTEC-UK, 2010).

The countries that imposed the most binding regulations initially were concerned that acid rain diffused across international borders. Those countries that lay downwind from important sources, and the Scandinavians in particular, began to envision a multilateral approach. This soon led to the Convention on Long Range Transboundary Air Pollution (LRTAP), signed in 1979, and endorsed by the United Nations Economic Commission for Europe. Initially there were 32 signatories in 1979 including major emitters of SO_X and NO_X such as the United States, Germany and the United Kingdom. The Convention has now been signed by 51 countries.

A range of technologies have been introduced in an effort to reduce emissions. In this paper, we focus on a subset of such technologies, and are particularly interested in the transfer of the technologies between countries. For local pollutants the adoption of abatement innovations at the national level is primarily beneficial for the country itself. However, since SO_X and NO_X pollution can sometimes travel hundreds of kilometres, often originating from a foreign source, there are potential environmental benefits (and not just economic benefits) from the transfer of technologies between countries. This has lead to the consideration of how to encourage the diffusion of new abatement technologies abroad.

To this end, the signatories to the Protocols arising out of the LRTAP Convention have identified technology transfer as a particular objective to encourage cost-effective reductions in environmental damages. The aim of this paper is to assess empirically whether the Protocols have had an impact on such technology transfer. To do so, we estimate a model to empirically test the hypothesis that the Protocols have had a positive impact on technology transfers between the signatories.

Before proceeding to a discussion of the model estimated, we first discuss the characteristics of the acid rain problem, and how it can be addressed. Following this, we present the data used and the model estimated. Finally, we discuss the empirical results and the implications of the findings.

The environmental, technological and policy background

Emission sources, environmental impacts and abatement technologies

Acid rain designates both wet and dry depositions from the atmosphere and containing an unusual amount of nitric and sulphuric acids. These acids come from the mixing of compounds released by combustion reactions and precipitation: sulphur dioxide (SO_2), nitrogen oxides (NO_X) and volatile organic compounds (VOCs). While natural sources, such as volcanoes, are also sources of these compounds, the most important sources are anthropogenic emissions from the combustion of fossil fuels. For example, electricity-generating plants were responsible for as much as 70% of all SO_X and 20% of all NO_X emissions in 2007 in the United States. In Germany, these proportions were 43% of SO_X and 20% of NO_X emissions, and in Japan, 25% and 15% respectively (OECD Environmental Data Compendium). (See Annex 2.A1 for data on SO_X and NO_X emissions for other OECD countries.) Industrial combustion of fossil fuels and the transportation sector also contribute significant shares. Importantly, airborne emissions of these compounds are easily transported for hundreds of kilometres by wind.

In addition to acid rain formation, the most visible impacts of acid rain include the presence of an abnormally high amount of nitrogen and sulphur in lakes and rivers with detrimental effects on the fish populations and aquatic biodiversity in those freshwater sources more generally. Sulphuric and nitric acids fall with precipitation, acidifying rivers, lakes and other surface waters, decreasing the pH of these aquatic environments by 1 or 2 points (usually the pH of these waters is around 6 or 7; some particularly affected lakes, such as the Little Echo Pond in the US, has a pH of 4.2) (INRA, 2009; USEPA, 2010). Acid rain also has a detrimental effect on soils in forested areas. The acid depositions kill the fertile compounds of forest soils resulting in *Waldsterben* or forest death (Dupuy, 2003).

While acid rain does not directly harm human health, the precursor pollutants to acid rain (SO_X and NO_X compounds) do have important human health effects (*e.g.* respiratory diseases). Lastly, the deposition of these acidic compounds can corrode monuments, statues, buildings or even cars. In the automobile industry for instance, acid rain is characterised as “environmental fallout”, in reference to the damage done to the paint and structure of cars by dry acid deposition (USEPA, 2010).

SO_X and NO_X are primarily emitted when fossil fuel is burned to produce energy. This occurs in electricity generating plants and in transportation when fossil fuels are combusted. So the key point in reducing emissions is to know how to control the combustion process, or how to increase its energy and environmental efficiency. Three approaches can be considered:

- Changing inputs at the pre-combustion process.
- Modifying the combustion itself (integrated approach).
- Approaching the problem after combustion (flue gas treatment).

Reducing emissions of sulphur and nitrogen particles can be achieved through the modification of the composition of the combustion input. First, the fuel can be changed for a cleaner one (for instance change from high-sulphur coal to low-sulphur coal). Second, the input can be cleaned (desulphurised). Another method is to reduce the emissions of the targeted compounds by modifying the combustion process itself. For instance, this can be achieved by using the waste heat of engines or gas turbines in power generation, by injecting lime stone (SO_X) or making the combustion occur in a fluidised bed of fuel or other particles. In the case of NO_X, the use of low-NO_X burners and flue gas recirculation can be effective means as well. Lastly, the end-of-pipe approach involves reducing emissions after combustion takes place. Catalytic or non-catalytic purification or flue gas desulphurisation are among the most efficient tools available today.

This paper focuses on the post-combustion abatement technologies (see Annex B for a list of patent classes used in the analysis reported in this section). Since the late 1960s when awareness of the acid rain problem grew, the development of these various abatement technologies has been a response to domestic policy measures. But, as noted above, one particularity of the targeted compounds (SO_X and NO_X) is that they can be carried by the wind thousands of kilometres away from where they were emitted. Emissions not only have an impact on a local scale, they are a transboundary problem.

International co-operation and the Protocols

As noted above, in the late 1960s Scandinavian countries were the first to recognise the magnitude of damages from acid rain. Leading scientists hypothesised that the pollution was due not only to local emissions, but also transboundary pollutant compounds carried over from neighbouring countries. While the Scandinavian countries began to pursue significant abatement of emissions, the rest of Europe did not immediately recognise that they too were being affected by acid rain, and did not initially introduce regulations to reduce emissions.

However, this soon changed and the Convention on Long Range Transboundary Air Pollution (LRTAP) was signed in November 1979 and implemented through the United Nations Economic Commission for Europe (see *www.unece.org/env/lrtap*). It has since been signed by 51 countries (32 countries in 1979 including major emitters of SO_X and NO_X as the United States, Germany and the United Kingdom). The Convention was more an official acknowledgment from the signatories that ecological damage from air pollution was significant and that transboundary air compounds were partly responsible.

At the time of signature, there were no real constraints on the signatories, and as such the countries had no real disadvantage in signing the Convention. Most of the countries that ultimately became signatories had already developed domestic policies, but of varying stringency. Indeed, in the years immediately following, the Convention did not appear to induce different behaviour among the signatories (Levy, 1995). However, the Convention initiated a process through which further agreements became feasible, and above all it has become a stable international agreement on transboundary pollution.

This political will to try to address the acid rain problem on a multilateral scale has resulted in four Protocols from 1985 to the latest one in 1999.[7] While the Protocols have a common approach on emissions reduction, they were nevertheless slightly different from each other:

- 1985: *the Helsinki Protocol* calling for a 30 per cent reduction of SO_X emissions by 1993 based on 1980 emission levels.
- 1988: *the Sofia Protocol* calling for stabilisation of NO_X emissions by 1994 based on 1987 emissions level.
- 1994: *the Oslo Protocol* calling for differentiated reductions in SO_X by country by 2000 (with some countries adopting scheduled reductions for 2005 and 2010).

- 1999: *the Gothenburg Protocol* giving a precise table of reduction goals in SO_X and NO_X for each signatory to be achieved by 2010.

The first Protocol (Helsinki) followed the decision of the German government to join the Scandinavians on reducing SO_2 emissions in the 1982 Stockholm conference on Acidification of the Environment (Levy, 1995). It was a first cautious step, establishing the emissions reduction system that would be used in future. However, the common 30% reduction (base year: 1980) was not binding enough, with some countries even complying with the commitment at the time of signature (at least 8 out of the 19 countries who signed in Helsinki were already in compliance with their commitments). The Protocol could be considered an agreement on the minimum commitment that should be achieved in the following decade. According to Levy (1995) it is the "Least-Common-Denominator Protocol". The following Protocols gave rise to more concrete co-operation.

The Sofia Protocol which followed only affected NO_X. It bound the countries to freeze NO_X emissions at their level in 1987 by 1995. The exchange of technologies was mentioned in one article of the Protocol, the first time since the signing of the Convention in 1979. The Protocol was, therefore, not only concerned with setting mutually agreed emission reduction plans, but co-operation in the means of meeting these commitments was encouraged. In principle, signing the Protocols was intended to increase mitigation capacity in each country by encouraging technology transfers and information sharing.

The Oslo Protocol, which only concerned SO_X emissions, included clauses concerning the exchange of technology and information on the level of acidification, as well as documentation on the characteristics of control technologies. A major change relative to Helsinki was the differentiation of emissions commitments, and negotiations started on the percentage reductions to be achieved by 2000. Some countries added deadlines for 2005 and 2010. The Protocol's overall aim was to reduce the level of depositions in most of Europe by 60% (Wettestad, 2001).

The latest of the Protocols – Gothenburg (signed in 1999) – introduced a major modification because, in addition to SO_X and NO_X, it also targets emissions of volatile organic compounds (VOCs) and particulate matter (PM). In this sense, the Gothenburg Protocol is the fulfilment of the LRTAP Convention which targeted all transboundary compounds. It was also more ambitious with respect to reduction targets and more countries took part in the Protocol, with 31 signatories by May 2000. It also appended Guidance Documents on the characteristics and performance of different control options (*www.unece.org/env/documents/2005/1999/eb/eb.air.1999.2.e.pdf*). Since the targets have to be reached by 2010, it can be assumed that there will be a new Protocol with further commitments for the years to come.

In conclusion, the Protocols added to the LRTAP Convention are quite diverse, with somewhat different aims. The first Protocol tried to assemble the countries and make a minimal commitment that was not particularly binding. The second introduced a new pollutant (NO_X) and put the exchange of technology and knowledge at the fore. The latest ones have included further precisions such as available technologies, emissions from mobile sources, differentiated commitments by countries and still more pollutants (VOCs and PM).

At the same time, a significant international collaborative research project was instituted. It arose out of previous OECD work in the early 1970s and has been continued under the name of the European Monitoring and Evaluation Programme (EMEP), which was created to provide high-quality scientific information on emissions and the diffusion of transboundary emissions covered by the LRTAP. This contributed to the understanding of which countries were the main emitters and how emissions travelled to other countries. It was the predecessor of the RAINS model (Regional Air Pollution INformation and Simulation) which was more accurate and had greater coverage (for more details on the RAINS model see *e.g.* Alcamo *et al.*, 1990).

Motivations to co-operate

This scientific work showed how important it was that some specific countries joined the agreement. As such, it is important to assess the possible motivations of the signatories. The difficulty here is that we only observe the outcomes of the choice of whether or not to sign an agreement, and not the process that drove the country to do so. Clearly, a given country will only join an international agreement if it brings net benefits. Several factors can influence the cost/benefit calculus, including the cost of compliance, demand for environmental quality, and geographic location (Beron *et al.*, 2003).

An individual country's decision to sign a Protocol will be affected by relative demand for environmental quality and the susceptibility of local ecological conditions to damage from acidification. (See Annex 2.A2 for a list of the signatories and their dates of signature.) The more vulnerable a country is to damage from acidification and the greater the demand for preservation of environmental quality, the greater the likelihood that the country will join an international agreement. In some countries, especially the UK and Germany, public awareness of the acid rain problem may have been influential in inducing the country to sign the Protocol (Levy, 1995).

Cost of compliance with the Protocol will also play a role. The cost of reducing SO_X and NO_X emissions arises through investment in abatement technologies, and with rising marginal abatement costs the country's ability to negotiate emission reduction commitments which are not excessively burdensome will affect whether they ultimately sign the Protocol. Any given commitment will be easier to meet with falling baseline emissions due to factors such as structural changes in the economy or fuel-switching in the electricity sector.

In one study (Mäler and de Zeeuw, 1998) it was found that a co-operative outcome was more likely if there are countries with high critical loads but low emissions who will reduce their emissions (but not by as much) and countries with low critical loads and high emissions who will have to reduce their emissions in any case. One can conclude that in this situation, it will be beneficial for all players to co-operate.

However, geographic location clearly plays a particularly important role. Local pollutants can be addressed efficiently with national policies, so an international agreement would only improve efficiency if two countries face the same type of pollution and want to share information or technology on how to address it. At the other pole are global pollutants such as ozone-depleting substances or CO_2 pollution. For this type of pollution, an international agreement is motivated by efficiency gains from addressing all sources of pollution, irrespective of location.

In the case of SO_X and NO_X, there is an asymmetry. As noted, the Scandinavians were the ones who pushed for the first Protocol. They were aware that reducing emissions on their own would not be sufficient to get emission levels below critical loads, which is the maximum level of acidification the environment is capable to absorb and eliminate itself

(Nilsson, 1986). Trans-frontier emissions from southern and continental Europe were sufficient to exceed critical loads on their own soil.

As such, the incentive for the Scandinavian countries to enter an international agreement was clear: to encourage “upwind” countries emitting pollutants to reduce emissions in order to reduce their downwind acidification levels. But what about the “upwind” countries, whose emissions do not exclusively fall within their borders, but diffuse to the neighbours? At first glance, they have no incentive to enter an international agreement which would commit them to reduce emissions, but bear the costs of doing so.

The best response is then to leave the agreement or to not sign it in the first place (Wagner, 2001). While free-riding would seem to be the best alternative for those countries that are situated upwind , in the end we witness a signature, suggesting that other factors play a role. From a game-theoretical framework, Mäler and de Zeeuw (1998) point out that a co-operative solution will occur if there are side payments, ensuring that countries jointly minimise their costs. Many such side payments may not be “visible” to the observer, or may manifest themselves in other “related” games. For instance, Wagner points out that mutual presence in other agreements can affect countries’ decision to sign (Wagner, 2001).

However, other forms of “payment” may be reflected in the agreements themselves. For instance, if the environmental leaders are downwind, they may be able to influence compliance costs in other countries. The innovation undertaken by those downwind countries will result in a spillover that lowers the marginal abatement costs in upwind neighbours, with increased abatement yielding benefits in the downwind countries. We could make the assumption that these side payments are realised by the technology transfers that occur from downwind countries to upwind countries.

The Protocols and technology transfer

Each Protocol has added a new dimension to the issue of technology transfer and knowledge diffusion in the combat against acid rain. In Annex 2.A3 we summarise what each Protocol said on the issue of technology transfer and knowledge sharing, but an overview is provided here.

The first Protocol did not explicitly mention technology transfer. However, the Sofia Protocol included a technology transfer clause that has been in the Protocols ever since. The Oslo Protocol added a clause regarding the sharing of research and development efforts in abatement technologies. It stated that any innovation discovered in one of the signatory shall be transferred to the other signatories. While in principle this information diffusion clause is strong, the mechanics of implementation of the clause are not elaborated. More recently, the Gothenburg Protocol reiterated all the previous clauses.

According to the Protocols, the signatories shall co-operate in some projects, but also share information on abatement technologies and promote exchange of technology and information. For instance, the detailed Guidance Documents that are provided may result in important knowledge spillovers among signatories (*www.unece.org/env/documents/2005/1999/eb/eb.air.1999.2.e.pdf*). However while the Protocols clearly advocate the promotion of technology transfer as a means of reducing pollution, they do not evoke any incentive on how the promotion of these transfers should happen.[8] Moreover, all documentation is unrestricted, with benefits accrued to all countries, whether they are parties to the Protocol or not.

In order to test empirically whether technology transfer had an effect on motivations to sign the Protocols, we compared the ratio between transfers of SO_X abatement technologies and total technology transfers from a downwind country to an upwind country with the same ratio but from the upwind country to the downwind country (see Annex D for the list of classes used in the patent extraction). We expected that the first ratio would be higher than the second if the down-wind country transferred technology as an incentive to get the upwind country into an agreement of emissions reduction.

Table 2.5 summarises this ratio for various pairs of countries. The first row displays the ratio from the downwind country to the upwind country, and the second the inverse ratio. The figures represent "the percentage of the total transfers that occurred between the two countries that actually concerned SO_X/NO_X abatement technologies". Of the eight country-pairs, seven present a transfer ratio that is higher in the case of a downwind to an upwind transfer for SO_X-specific abatement technologies. In the case of NO_X-specific abatement technologies only four of eight do so.[9] The same is true for the third category of technologies designed for simultaneous SO_X and NO_X abatement.

Table 2.5. **Relative importance of transfers of SO_X/NO_X abatement technologies**

Assumed wind direction	Source of ITT	Recipient of ITT	SO_X (%)	NO_X (%)	Simultaneous SO_X and NO_X (%)
←	CA	US	0.0649	0.0295	0.0118
→	US	CA	0.0628	0.0409	0.0142
←	SE	GB	0.0561	0.0000	0.0000
→	GB	SE	0.0000	0.0000	0.0000
←	FI	GB	0.5544	0.0693	0.0693
→	GB	FI	0.0187	0.0374	0.0000
←	DE	GB	0.0916	0.0438	0.0319
→	GB	DE	0.0179	0.0339	0.0000
←	DK	GB	0.1911	0.1911	0.1911
→	GB	DK	0.0168	0.0251	0.0000
←	SE	DE	0.1421	0.0398	0.0114
→	DE	SE	0.1176	0.1372	0.0588
←	FI	DE	0.1252	0.0385	0.0096
→	DE	FI	0.1279	0.1279	0.0295
←	DK	DE	0.2484	0.1988	0.0497
→	DE	DK	0.2060	0.1797	0.0337

While this data is of interest, the primary purpose of this paper is not to determine the motivation of a given country to sign a given Protocol, but rather the more general question of whether the Protocols have lead to more technology transfer between the signatories and if these political agreements have a real impact on the number of technologies actually transferred from one country to another.

Presentation of the data and the model

Our measures of technology transfer in SO_X/NO_X abatement technologies cover the period from 1980 to 2008. For many pairs of countries and individual years there is no evidence of transfer whatsoever. However, in other cases the flows represent non-negligible proportions of total transfer. Tables 2.6 and 2.7. list the top ten country-pairs with the highest amount of patents transferred in SO_X and NO_X abatement technologies.

Table 2.6. **Major source and recipient countries in SO_X abatement technologies**

Number of duplicate patent applications, 1980-2008

Source country	Recipient country										Total
	US	JP	CA	DE	AU	ES	DK	AT	PL	KR	
US		148	191	117	105	51	22	43	36	28	**741**
DE	138	118	67		46	49	55	69	23	9	**574**
JP	153		36	102	12	42	57	11	36	41	**490**
FR	36	35	18	38	11	30	13	11	6	9	**207**
SE	20	30	16	25	32	9	19	12	16	1	**180**
FI	23	11	22	13	22	11	7	3	14	1	**127**
NL	7	10	9	13	9	9	9	12	5	1	**84**
GB	9	14	12	10	12	5	2	2	2		**68**
AT	11	7	5	17	4	2	4		3		**53**
DK	11	11	5	10	5	4		2	3	2	**53**
Total	**408**	**384**	**381**	**345**	**258**	**212**	**188**	**165**	**144**	**92**	**2 577**

Note: Source country = office of priority application, recipient country = office of duplicate application. Applications from/to regional or international patent offices are not included. The two-letter codes represent the following patent offices: Austria (AT), Australia (AU), Canada (CA), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), Great Britain (GB), Japan (JP), Korea (KR), the Netherlands (NL), Norway (NO), Poland (PL), Sweden (SE), the United States of America (US).

Source: EPO (2010), "Global Patent Data Coverage", January.

Table 2.7. **Major source and recipient countries in NO_X abatement technologies**

Number of duplicate patent applications, 1980-2008

Source country	Recipient country										Total
	US	JP	DE	CA	AU	AT	ES	KR	DK	NO	
DE	204	164		59	56	70	61	15	48	35	**712**
US		162	98	124	126	45	29	45	16	18	**663**
JP	191		115	39	15	20	8	40	11	9	**448**
FR	42	32	28	22	14	19	19	7	8	9	**200**
GB	27	24	19	7	18	13	9	5	3	3	**128**
SE	12	12	7	6	7	3	4	1	4	4	**60**
NL	11	6	7	5	8	6	5	2	3	5	**58**
FI	8	6	4	9	7	3	3	1		2	**43**
AT	9	3	8	4	1		1	1	3		**30**
DK	4	3	8	3	2	1	3	1		1	**26**
Total	**507**	**412**	**294**	**278**	**254**	**180**	**142**	**118**	**96**	**86**	**2 367**

Note: Source country = office of priority application, recipient country = office of duplicate application. Applications from/to regional or international patent offices are not included. The two-letter codes represent the following patent offices: Austria (AT), Australia (AU), Canada (CA), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), Great Britain (GB), Japan (JP), Korea (KR), the Netherlands (NL), Norway (NO), Poland (PL), Sweden (SE), the United States of America (US).

Source: EPO (2010), "Global Patent Data Coverage", January.

In order to assess in a preliminary manner whether joint signature of the Protocols affected the rate of transfer of abatement technologies a binary variable was created indicating whether a particular country had signed a Protocol by a given year. This can be compared with the rate of transfer for abatement technologies relative to all technologies. As can be seen in Table 2.8 the rate of transfer for both SO_X and NO_X abatement technologies is greater between signatories than between other pairs. Specifically, the ratio is higher when both countries are signatories (bottom-right cell of the tables) than when neither are signatories (top-left), and when one has signed but not the other.

Table 2.8. **Technology transfer and protocol signature**

% of total transfer – by country pair and year

		Recipient country	
		0	1
SO_X transfers			
Source country	0	0.0256	0.0168
	1	0.0349	0.0376
NO_X transfers			
Source country	0	0.0156	0.0082
	1	0.0252	0.0440

However, many factors are likely at play in determining the pattern and extent of transfer of abatement technologies. As such, we will now construct an econometric model and try to estimate the effect of the signature of the Protocols on transfers of abatement technologies.

It is important to control statistically for differences in the general propensity to transfer inventions between pairs of countries. In order to capture the effect of such factors (which are not specific to environmental technologies), we include the variable $TOTTALTT_{ijt}$ reflecting the total number of duplicate patent applications across the whole spectrum of technological fields, between 1980 and 2008, for all countries concerned by our study. To re-iterate, the $TOTALTT_{ijt}$ variable thus controls for the general *rate* of transfer, while the remaining explanatory variables capture the factors that may "bend" the *direction* of transfer towards more environmental ends. Similarly as our dependent variable, $TOTALTT_{ijt}$ varies across all three vectors (time, source, recipient).

Our primary variable of interest is a variable reflecting joint signature of the Protocols by source and recipient countries ($SIGN\_SOX_{ijt}$ and $SIGN\_NOX_{ijt}$). This varies across country pairs and years. It takes the value "1" if both source (*i*) and recipient (*j*) countries have signed the Protocol in question in year t, and "0" otherwise. For example the Helsinki joint dummy equals 1 if *i* and *j* are signatories of the Helsinki Protocol in year *t* ($1985 \leq t \leq 1993$). We aggregate the Protocols' joint dummies in order to get a measure that considers the series of Protocols as though they were a single agreement with different amendments. The SO_X joint dummy contains the signature's status for Helsinki, Oslo and Gothenburg; while the NO_X joint dummy concerns the Sofia and the Gothenburg Protocols.

We also introduce other variables that are likely to have an effect on the technology transfer in order to isolate the effect of joint Protocol signature between pairs of countries. On the basis of previous work (see *e.g.* Haščič and Johnstone, 2011) a number of factors have been identified that can have a significant influence on the amount of transfer.

Policy stringency is clearly an important determinant of demand for environmental technologies in the recipient country. As a measure of policy stringency we created a variable which is the count of all patents filed in the previous four years in the office of the country receiving the technology transfer ($ENVPOL_{jt}$). If a country introduces commitments on emissions for any pollutants, then the industries will need to implement abatement techniques and technologies. It creates a demand for the adoption of abatement technologies, whether invented at home or abroad.[10] We assume that a more stringent policy will be reflected in the number of patents filed in this particular office. We expect its estimated sign to be positive.

$SRCPAT_{it}$ is the count of all patent applications in which the source country in question is the office of the "priority" application. The variable is constructed as the sum of the counts for the years *t*, *t*–1, *t*–2 and *t*–3 to reflect the fact that patentees have as long as 30 months after the priority date in which they are able to seek protection in other countries.[11] This variable allows us to control for the stock of available abatement technologies that could potentially be transferred from the source country. We expect this variable to have a positive coefficient.

The final variable ($ABSCAP_{jt}$) serves as a measure of the capacity of the recipient country to adapt foreign and new technologies. This capacity is measured as the % of skilled occupations on total workforce in the main industries concerned by SO_X/NO_X emissions abatement (manufacturing and electricity, gas and water supply). The occupations we focus on are described in the major groups 0/1 and ⅞/9 in the classification ISCO-1968 ("professional, technical and related workers" and "production and related workers, transport equipment operators and labourers") and the major group 3 in the classification ISCO-88 ("technicians and associate professionals"). Our variable is constructed as the percentage of people occupying these types of jobs regarding the total of active population in those industries. The data has been obtained from the *LABORSTA Database* of the International Labour Organisation (ILO). The descriptive statistics for each variable that will be used in the model are presented in Table 2.9.

Table 2.9. **Descriptive statistics of the variables of interest**

Variable	Unit	Obs.	Mean	Std. dev.	Min.	Max.
Full sample						
SOXTT	Count	14 419	0.1526	0.8259	0	21
NOXTT	Count	14 419	0.1378	0.8456	0	26
SIGN_SOX	Dummy	14 419	0.2150	0.4108	0	1
SIGN_NOX	Dummy	14 419	0.2352	0.4242	0	1
SRCPAT_SOX	Count	14 419	31.6494	97.4865	0	716
SRCPAT_NOX	Count	14 419	28.8916	88.9112	0	703
ENVPOL_SOX	Count	14 419	72.0012	146.2377	0	789
ENVPOL_NOX	Count	14 419	62.1170	124.7657	0	765
ABSCAP	Share	14 419	0.4906	0.3264	0	0.9342
TOTALTT	Count	14 419	267.4171	1 475.7060	1	4 4634
Sub-sample						
SOXTT	Count	9 335	0.2290	1.0110	0	21
NOXTT	Count	9 335	0.2069	1.0386	0	26
SIGN_SOX	Dummy	9 335	0.2969	0.4569	0	1
SIGN_NOX	Dummy	9 335	0.3275	0.4693	0	1
SRCPAT_SOX	Count	9 335	35.3775	104.3533	0	716
SRCPAT_NOX	Count	9 335	32.5987	96.0765	0	703
ENVPOL_SOX	Count	9 335	78.4829	151.1499	0	789
ENVPOL_NOX	Count	9 335	66.0847	127.8879	0	765
ABSCAP	Share	9 335	0.4952	0.3184	0	0.9087
TOTALTT	Count	9 335	397.4488	1 817.5380	1	4 4634

Note: The full sample is a panel of 29 years (1980-2008), 87 source countries and 65 recipient countries. The sub-sample includes only the 34 OECD member countries.

The model

In this paper a similar methodology is used to that which was applied in Eaton and Kortum (1996) for all technology fields. The following equations are specified for the purpose of our discussion above:

$SOXTT_{ijt} = f\,(SIGN\_SOX_{ijt}, SRCPAT\_SOX_{it}, ENVPOL\_SOX_{jt}, ABSCAP_{jt}, TOTALTT_{ijt}, \gamma_i, \delta_j, \omega_t) + \varepsilon_{ijt,}$

and

$NOXTT_{ijt} = f\,(SIGN\_NOX_{ijt}, SRCPAT\_NOX_{it}, ENVPOL\_NOX_{jt}, ABSCAP_{jt}, TOTALTT_{ijt}, \gamma_i, \delta_j, \omega_t) + \varepsilon_{ijt}$

where *i* represents the source country, *j* the recipient (host) country, and *t* the year considered (1980-2008). The variables are those we just described and γ_i, δ_j, ω_t are the fixed effects to account for any omitted time- and country-specific (respectively host and source country) heterogeneity. ε_{ijt} captures the residual variation as an error term.

The dependent variable $SOXTT_{ijt}$ is the count of patent applications associated with a specified technology that are "transferred" from country *i* (priority office) to country *j* (duplicate office). So it is a count variable which can be estimated after transformations by the least squares. However, given the count structure of the data the estimates would be biased, and the coefficients difficult to interpret. Moreover, we also have a high proportion of zero outcomes.

One possible solution would be to estimate using the Poisson model, but the use of Poisson is dependent upon the strong assumption of equality between the mean and the variance (equidispersion), which is inappropriate when there is over-dispersion in the data. So in order to take into account such variability we will rather use a negative binomial model. The negative binomial model is attractive because it allows relaxing the strong equidispersion assumption.

The regression coefficients are estimated with a maximum likelihood method.[12] In the estimation sample we only include observations for which the pair of countries experienced a positive technology transfer in any technological field in that specific year, *i.e.* we restrict the estimation sample to cases when total transfer is non-zero (TOTALTT > 0). The reason for this is that, as explained above, we are interested in whether environmental policy characteristics bend the "direction" of transfer towards more environment-related technologies. This gives us a maximum sample size of 14 419 observations.

Results and discussion

First, we use the SO_X abatement technology transfer variable as a dependent variable, then we estimate with the NO_X abatement technology as the dependent variable. For each case the models are estimated with fixed effects absent (Model 1) and with both year and host country fixed effects included (Model 2). Including also the source country fixed effects poses significance problems for the signature dummy variable, which was predictable.

The estimation results for the SO_X model are displayed in Table 2.10. In both variants of the model, the estimation shows, as expected, that the explanatory variables which reflect general propensity to transfer technologies (TOTALTT), the potential supply of innovations (SRCPAT), the stringency of host country policy (ENVPOL), and the host country

Table 2.10. **Estimated coefficients of the SO_X model**

Dependent variable: $SOXTT_{ijt}$	Full sample		OECD countries	
	(1)	(2)	(3)	(4)
Protocols – joint signatories ($SIGN_{ijt}$)	1.0472***	1.1303***	0.7262***	0.8094***
	(0.1494)	(0.1349)	(0.1513)	(0.1415)
Level of innovation in source country ($SRCPAT_{it}$)	0.0047***	0.0052***	0.0044***	0.0046***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Patenting in recipient country ($ENVPOL_{jt}$)	0.0018***	0.0032***	0.0016***	0.0034***
	(0.0004)	(0.0009)	(0.0004)	(0.0009)
Skilled workforce in recipient country ($ABSCAP_{jt}$)	2.4770***	0.5973	2.4529***	0.5156
	(0.2022)	(0.3645)	(0.2162)	(0.3681)
Overall technology transfer ($TOTALTT_{ijt}$)	6.14E-04***	4.51E-04***	4.66E-04***	3.69E-04***
	(1.57E-04)	(1.03E-04)	(1.02E-04)	(7.97E-05)
Intercept	–4.8448***	–8.6418***	–4.3253***	–3.2464***
	(0.1880)	(0.6203)	(0.2029)	(0.4802)
Dispersion parameter (alpha)	4.2693***	2.8765***	3.2954***	2.3567***
	(0.6791)	(0.5325)	(0.5352)	(0.4435)
Year fixed effects	–	Yes	–	Yes
Recipient country fixed effects	–	Yes	–	Yes
N of obs.	1 4419	1 4419	9 335	9 335
N of country-pairs	2 238	2 238	960	960
Log Pseudolikelihood	–4 113.88	–3 848.99	–3 691.26	–3 487.11
Wald chi2	293.79	17 999.49	250.53	4 636.34
(Prob > Chi2)	0.000	0.000	0.000	0.000

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Robust standard errors adjusted for country-pair clusters are in parentheses.

absorptive capacity (ABSCAP) have a positive and statistically significant effect on the number of environmental technologies transferred. The exception is our measure of absorptive capacity when both year and recipient-country fixed effects are included. This may be a consequence of the relative "inertia" of this variable through time for a given recipient country.

Our primary interest focuses on the joint signature dummy (SIGN_SOX). In all models, the estimated coefficient has a positive sign and is statistically highly significant. This suggests that when both source and recipient countries are signatories to the Protocols, the number of inventions that are transferred increases, holding all other effects fixed. For the sub-sample of OECD countries, the estimated impacts are lower, although still positive and significant. The reason may be that the impact of joint signature is greater for countries with less intensive economic ties, lower absorptive capacity, or lower stringency of their environmental policy. The relative magnitudes of these effects are compared and discussed below. For the moment, we conclude that the Protocols have a positive and statistically highly significant effect on technology transfer, which validates our main hypothesis.

In the case of the NO_X model (Table 2.11), the estimated coefficients are always positive and significant, with the exception of the measure of absorptive capacity which is insignificant when fixed effects are included (Models 6 and 8). The reasoning discussed above may apply here as well. The effect of domestic environmental policy stringency is not as strong as was the case in the SO_X models. Conversely, the absorptive capacity has a much greater effect in the model without fixed effects.

Table 2.11. **Estimated coefficients of the NO_X model**

Dependent variable: $NOXTT_{ijt}$	Full sample		OECD countries	
	(5)	(6)	(7)	(8)
Protocols – joint signatories ($SIGN_{ijt}$)	1.2093***	1.7901***	0.9876***	1.5680***
	(0.1274)	(0.1764)	(0.1310)	(0.1971)
Level of innovation in source country ($SRCPAT_{it}$)	0.0053***	0.0070***	0.0051***	0.0065***
	(0.0006)	(0.0006)	(0.0006)	(0.0007)
Patenting in recipient country ($ENVPOL_{jt}$)	0.0013**	0.0015*	0.0014**	0.0014*
	(0.0005)	(0.0007)	(0.0005)	(0.0007)
Skilled workforce in recipient country ($ABSCAP_{jt}$)	1.1820***	0.0643	1.2898***	0.0626
	(0.1813)	(0.3308)	(0.1958)	(0.3322)
Overall technology transfer ($TOTALTT_{ijt}$)	7.22E-04***	4.76E-04***	5.79E-04***	3.98E-04***
	(1.70E-04)	(1.18E-04)	(1.33E-04)	(9.87E-05)
Intercept	–4.4648***	–3.9653***	–4.0946***	–3.6753***
	(0.1567)	(1.2041)	(0.1764)	(0.4656)
Dispersion parameter (alpha)	4.6357***	2.9122***	3.8401***	2.4793***
	(0.7482)	(0.4638)	(0.6208)	(0.4069)
Year fixed effects	–	Yes	–	Yes
Recipient country fixed effects	–	Yes	–	Yes
N of obs.	1 4419	1 4419	9 335	9 335
N of country-pairs	2 238	2 238	960	960
Log Pseudolikelohood	–3511.82	–3 250.72	–3173	–2 963.53
Wald chi2	305.29	9 655	228.04	6 916.8
(Prob > Chi2)	0.000	0.000	0.000	0.000

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Robust standard errors adjusted for country-pair clusters are in parentheses.

The coefficient on the signature dummy (SIGN_NOX) is much higher than is the case with the SO_X models. Similarly as above, the corresponding estimates for the OECD sample are lower than for the full sample. The relatively greater importance of the Protocols in the case of NO_X might be explained by the fact that Sofia and Gothenburg emphasised transfer to a greater extent.

The explanatory variables used in our models include a dummy, a share, and nonnegative counts. As such it is difficult to compare the relative magnitudes of the estimated coefficients and interpret them in a meaningful manner. To do so, we conducted an in-sample simulation exercise and compare the impacts of three variables that are of primary interest – the Protocols, domestic absorptive capacity, and environmental policy demand. Specifically, we construct a scenario in which all countries (or rather, country-pairs) would become joint signatories to the Protocols. We express the "benefit" of such a policy scenario in terms of the change in the predicted values of technology transfer (TT) under the scenario compared to a baseline (observed sample values). Then we ask what changes in the other variables of interest would be necessary to obtain an equivalent outcome in terms of an increase in TT. Table 2.12 summarises the results.

Results for model 1 suggest that increasing the proportion of joint signatories from the observed 22% to 100% (an increase by 78 percentage points) is equivalent to an increase in these countries' ABSCAP by 59 percentage points.[13] A corresponding result for the sub-sample of OECD countries (Model 3) is an increase by 35 percentage points – a lower value being expected given the coefficient estimates presented above. At first, these results would seem to indicate that changes in recipient countries' ABSCAP are relatively more important than accession to the Protocols. However, results from Models 2 and 4 suggest

Table 2.12. **Importance of selected regressors in their effect on predicted technology transfer**

Policy scenario: All country-pairs become joint signatories

	SO_X models				NO_X models			
	Full sample		OECD countries		Full sample		OECD countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SIGN (in % points)								
Observed (%)	22	22	30	30	24	24	33	33
New joint signatories (%)	78	78	70	70	76	76	67	67
	(1.9 σ)	(1.9 σ)	(1.5 σ)	(1.5 σ)	(1.8 σ)	(1.8 σ)	(1.4 σ)	(1.4 σ)
Equivalent change in ABSCAP (in % points)[1]								
All country-pairs (%)	49	> 100	24	> 100	> 100	> 100	> 100	> 100
	(1.5 σ)	(> 3.1 σ)	(0.7 σ)	(> 3.1 σ)	(> 3.1 σ)	(> 3.1 σ)	(> 3.1 σ)	(> 3.1 σ)
New joint signatories (%)	59	> 100	35	> 100	> 100	> 100	> 100	> 100
	(1.8 σ)	(> 3.1 σ)	(1.1 σ)	(> 3.1 σ)	(> 3.1 σ)	(> 3.1 σ)	(> 3.1 σ)	(> 3.1 σ)
Equivalent change in ENVPOL (number of patents)[2]								
All country-pairs (%)	508	304	346	188	> 765	> 765	552	> 765
	(3.5 σ)	(2.1 σ)	(2.3 σ)	(1.2 σ)	(> 6.1 σ)	(> 6.1 σ)	(4.3 σ)	(> 6.1 σ)
New joint signatories (%)	595	354	452	242	> 765	> 765	727	> 765
	(4.1 σ)	(2.4 σ)	(3.0 σ)	(1.6 σ)	(> 6.1 σ)	(> 6.1 σ)	(5.7 σ)	(> 6.1 σ)

Note: Changes expressed with respect to a baseline which was calculated using observed sample values. Values expressed as multiples of the sample standard deviation (σ) are in parentheses.

1. % point increase bounded to 100.
2. Increase bounded to sample maximum.

that even an increase to 100% would not suffice to achieve equivalence with Protocols. As such this result runs counter the previous one, although the ABSCAP estimate in Models 2 and 4 is insignificant.

How does this compare with environmental policy demand (ENVPOL)? For Model 1, an increase by 595 patented SO_X-related inventions (about 4.1 standard deviations) would be necessary in order to achieve an increase in SO_X technology transfer equivalent to Protocol accession. This is a much greater increase than the one in ABSCAP (1.8 standard deviations) or in joint signatories (1.9 standard deviations), indicating that acceding to the Protocols may be a good alternative for countries where improvements in domestic environmental policies are not forthcoming. As one would expect, such improvements are more likely to occur within the sample of OECD countries – and this is confirmed by our results – the increase in terms of standard deviations is about identical between ENVPOL and SIGN (1.6 and 1.5 respectively, Model 4).

Results for the NO_X models are less revealing, as most of the predicted effects would require a change that is greater that the sample (or theoretical) maximum. In summary, to obtain an effect that is equivalent to the scenario change in joint signature (1.4-1.8 standard deviations), out-of-sample values of ABSCAP and ENVPOL would be required This indicates that Protocol accession was a meaningful strategy to encourage transfer of NO_X abatement technologies.

In summary, whether it concerns SO_X or NO_X, we can say that for a given country-pair a joint signature increases the probability that there will be transfer of abatement technologies between these particular countries, when all other factors are held constant.

Conclusions

Technology transfer is key to realising environmental objectives at least cost. Moreover, the benefits of such transfer are greatest when impacts are trans-frontier in nature. The propensity for international diffusion of environmental technologies is a function of both domestic policy frameworks and international environmental co-operation. Drawing on a rich database of patent applications, we presented results on the effects of environmental policy design and multilateral environmental agreements on the international transfer of environmental technologies.

More specifically, on the one hand we have argued that "differentiated" and "prescriptive" technology-based regulations can result in fragmented technology markets, with the potential market for the innovations induced split across different policy jurisdictions. International policy co-ordination would reduce the potential for such fragmentation. For global public goods (*e.g.* mitigation of climate change) such co-ordination is evident. The European Union's Emissions Trading Scheme is the most significant example. However, even for greenhouse gas emissions within Europe, this is the exception and not the rule. For many sources there a myriad of differentiated and prescriptive policy measures.

The problem is, of course, more important in the case of local and regional pollutants. Indeed the imposition of uniform standards across countries with different ecological and economic conditions would not likely improve welfare. However, this does not mean that the benefits associated with globalised markets for innovation cannot be realised. "Flexibility" of policy regimes (rather than relative stringency) ensures that markets are not fragmented. Given the risks associated with expenditures on research and development, and the economies of scale required to recover such expenditures, it is important that regulatory regimes not constrain the potential markets for any induced innovations.

This flexibility is primarily a consequence of the point of incidence of different policy measures. Any policy that focuses on the environmental "bad", rather than mandating a certain means of reducing its impact, will provide potential innovators with the flexibility to identify the optimal means of its mitigation. This can include performance standards as well as market-based instruments such as environmentally related taxes and tradable permits. The key is that the policy measure be "technology neutral" in the sense that innovators have the choice of technology to use to meet a given environmental objective (*e.g.* SO_2 emission levels, wastewater effluent quality).

From our results there appears to be a strong relationship between CEO's perception of the flexibility of environmental policy regimes in different countries and the spatial scope of diffusion of inventions that are first patented in these countries. These results provide further support for the use of "flexible" instruments (including well-designed market-based instruments and performance standards) in environmental policy. And while the focus of this chapter was on the specific case of environmental policy, the discussion is equally applicable to aspects of product and labour market regulation that have implications for technological innovation, such as product and workplace safety.

On the other hand, we examined the role of international co-operation in encouraging the transfer of abatement technologies which mitigate acid rain. Indeed, the trans-frontier nature of SO_X and NO_X emissions make an international agreement essential to try to avoid over-acidification of environments at reasonable cost. We have noted that there are some factors which determine the likelihood that such co-operation will take place: the presence of leaders, the number or participants in the Protocols, etc. Moreover, we have seen that a specific type of game takes place for the acid rain issue. Because of natural and geographic conditions, in particular location of a country regarding the direction of wind, taking part in an international agreement can be costly relative to free riding. In such a case, the agreement will be unstable because all countries will not join.

We hypothesised that transfer of technology between signatories can be a way of encouraging adherence, providing an inducement for upwind countries to participate. Some empirical results provide descriptive evidence of the plausibility of such an assumption, but more formal analysis might be addressed in future work. In particular, we believe that a similar econometric model to ours, which directly reflects ecological conditions (wind direction), can help in testing this hypothesis. Moreover it would be interesting to broaden the spectrum of technologies considered. We only focus on post-combustion abatement technologies, which are however, the most commonly used.

However, the primary focus of this paper has been an assessment of whether the Protocols arising out of the LRTAP have encouraged the transfer of technologies between signatories. Indeed the major finding of this paper is that there is an effect on technology transfer for a country which joins the Protocols. We studied both SO_X and NO_X abatement technology transfer between countries which are joint signatories of the LRTAP Protocols and those who are not. In both cases, there is a positive effect on transfer between those pairs of countries who are joint signatories.

We can assume therefore that inducements related to technology transfer can play a positive role in encouraging the stability of international environmental agreements. However, it is revealing that the text of the Protocols says very little about the mechanics of such transfer, and the specific role that the Protocols can play in encouraging it. The simple sharing of information on available abatement technologies – *i.e.* through regular conferences and documentation – may be the factor which lies behind these results. Moreover, sharing of information on the choice and design of particular policies to encourage abatement may play a role as well.

However, it is possible that financial incentives could be provided. For instance, innovating countries that lie downwind from important sources could provide preferential access to protected inventions as an inducement for upwind sources. This would encourage the upwind countries to sign the Protocols and commit to emissions reductions. However, the owners of the IPRs in the downwind countries would likely demand compensation.

In general, it is heartening to find that international environmental agreements have encouraged the transfer of technologies that are essential to reduce pollution and to bring about environmental improvements. This is likely to become more important in future years. In particular, emerging economies, such as India and China which have fast-growing industries in the most polluting sectors are significant emitters of SO_X and NO_X. In some cases wind patterns plays an important role in diffusing emissions across border (China, Korea and Japan for example), and the need to induce increased abatement through technology transfer is particularly pressing in such cases.

Notes

1. Standardisation is, of course, important in the presence of network externalities (see Shy, 2001). However, this is of limited relevance to environmental concerns.
2. Lags associated with filing duplicate applications are, in part, determined by the Paris Convention (1883), stipulating that applications abroad must be filed within one year of the date when the initial application was filed (referred to as "priority date"). If the inventor does file abroad within one year, the inventor will have priority over any similar patent applications received in those countries since the priority date. In addition, under the Patent Co-operation Treaty (1970), the applicant may file an international application that allows further 18 months to make any duplicate filings in signatory countries.
3. There are 101 source and recipient countries in the sample. This includes the 34 OECD member countries as well as Brazil, Russia, India, Indonesia, China, South Africa and others.
4. That is, three years after and three years prior to the availability of data on the flexibility index.
5. A previous study (Dekker *et al.*, 2009) has used difference in the factors which encourage applications of different types of patents (claimed priorities and duplicates) to assess the role of the Protocols in encouraging both the development and international diffusion of abatement technologies. The work reported on in this section focuses only on the latter issue, using a somewhat different methodology.
6. "Acid rain" designates either dry or wet acid deposition, with elevated levels of hydrogen ions (equivalent to low *pH*).
7. According to the preamble to the Protocols each country is "aware of the fact that the predominant sources of air pollution contributing to the acidification of the environment are the combustion of fossil fuels for energy production, and the main technological processes in various industrial sectors, as well as transport, which lead to emissions of sulphur dioxide, nitrogen oxides, and other pollutants" and considered "that high priority should be given to reducing sulphur emissions, which will have positive results environmentally, on the overall economic situation and on human health".
8. While there is indeed no explicit discussion of the possible mechanism of encouraging such transfers, the Protocols also include documents providing information on the policy options available. This includes a review of the various approaches governments may adopt in regulating SO_X/NO_X emissions. For some countries, this type of information sharing could thus serve as another channel for creating demand for transfer of abatement technologies.
9. This may be because post-combustion technologies are generally more suitable for SO_X abatement. Beyond certain abatement levels, integrated approaches may be needed to achieve further NO_X reductions.
10. As such, the count includes claimed priorities, singulars and duplicates.
11. A maximum of 12 months under the Paris Convention (1883) and additional 18 months under the Patent Co-operation Treaty (1970).
12. We used STATA's procedure nbreg to fit the models and the option technique (dfp) in order to use the Davidon-Fletcher-Powell iteration method. This allowed us to introduce fixed effects, which was not possible using the default Newton-Raphson technique.
13. For example, increasing the share of skilled workforce from 0 to 0.59, or from 0.20 to 0.79. The increase in the share is bounded at 1.

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ANNEX 2.A1

Emissions of SO_X and NO_X in OECD Countries

	SO_X emissions in 2007 (1 000 tonnes)	Change on 1990 (%)	NO_X emissions in 2007 (1 000 tonnes)	Change on 1990 (%)
Canada	1 905	–39	2 275	–5
United States	11 635	–44	15 317	–33
Japan	780	–23	1 943	–5
Australia	2 490	56	1 762	41
New Zealand	73	36	158	47
Austria	26	–66	219	14
Belgium	126	–66	259	–31
Czech Republic	217	–88	285	–62
Denmark	23	–87	167	–39
Finland	82	–67	183	–38
France	435	–67	1 344	–31
Germany	494	–91	1 294	–55
Greece	543	15	374	26
Hungary	84	–92	190	–20
Iceland	11.3	56	25.6	–6
Ireland	54	–70	117	–6
Italy	339	–81	1 147	–43
Luxembourg	1.3[1]	–93	13.7	–41
Netherlands	59	–69	280	–48
Norway	20	–62	193	–7
Poland	1 131	–65	885	–44
Portugal	185	–42	255	0
Slovak Republic	71	–87	83	–61
Spain	1 156	–47	1 499	20
Sweden	34	–68	167	–45
Switzerland	14	–67	80	–50
Turkey	1 612	6	1 200	85
United Kingdom	590	–84	1 481	–46

Note: Total emissions, including mobile and stationary sources.

1. Refers to 2006.

Source: OECD Environmental Data Compendium.

ANNEX 2.A2

Signatories of the LRTAP Convention and Selected Protocols

		LRTAP	Helsinki		Sofia		Oslo		Gothenburg	
		Ratif	Sign	Ratif	Sign	Ratif	Sign	Ratif	Sign	Ratif
Albania	AL	2005		×		×				
Armenia	AM	1997							×	
Austria	AT	1979	×	×	×	×	×	×	×	
Azerbaijan	AZ	2002								
Belarus	BY	1979	×	×	×	×	×	×		
Belgium	BE	1979	×	×	×	×	×	×	×	×
Bosnia and Herzegovina	BA	1992								
Bulgaria	BG	1979	×	×	×	×	×	×	×	×
Canada	CA	1979	×	×	×	×	×	×	×	
Croatia	HR	1992				×	×	×	×	×
Cyprus[1, 2]	CY	1991				×		×		×
Czech Republic	CZ	1993		×		×	×	×	×	×
Denmark	DK	1979	×	×	×	×	×	×	×	×
Estonia	EE	2000		×		×				
Finland	FI	1979	×	×	×	×	×	×	×	×
France	FR	1979	×	×	×	×	×	×	×	×
Georgia	GE	1999								
Germany	DE	1979	×	×	×	×	×	×	×	×
Greece	GR	1979			×	×	×	×	×	
Hungary	HU	1979	×	×	×	×	×	×	×	×
Iceland	IS	1979								
Ireland	IE	1979	×	×	×	×	×	×	×	
Italy	IT	1979			×	×	×	×	×	
Kazakhstan	KZ	2001								
Kyrgyzstan	KG	2000								
Latvia	LV	1994							×	×
Liechtenstein	LI	1979	×	×	×	×	×	×	×	
Lithuania	LT	1994		×		×		×		×
Luxembourg	LU	1979	×	×	×	×	×		×	×
Malta	MT	1997								
Monaco	MC	1999						×		
Montenegro	ME	2006								
Netherlands	NL	1979	×	×			×	×	×	×
Norway	NO	1979	×	×	×	×	×	×	×	×
Poland	PL	1979			×		×		×	
Portugal	PT	1979							×	×
Moldova	MD	1995							×	

		LRTAP	Helsinki		Sofia		Oslo		Gothenburg	
		Ratif	Sign	Ratif	Sign	Ratif	Sign	Ratif	Sign	Ratif
Romania	RO	1979							×	×
Russian Federation	RU	1979	×	×	×	×	×			
San Marino	SM	1979								
Serbia	RS	2001								
Slovak Republic	SK	1993	×	×		×	×	×	×	×
Slovenia	SI	1992				×	×	×	×	×
Spain	ES	1979			×	×	×	×	×	×
Sweden	SE	1979	×	×	×	×	×	×	×	×
Switzerland	CH	1979	×	×	×	×	×	×	×	×
The FYR of Macedonia	MK	1997		×	×	×		×		
Turkey	TR	1979								
Ukraine	UA	1979	×	×	×	×	×		×	×
United Kingdom	GB	1979			×	×	×	×	×	×
United States	US	1979			×	×			×	×

Note: Assistance of Andreas Ferrara in compiling the Protocol data is gratefully acknowledged.

1. Footnote by Turkey: the information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".
2. Footnote by all the European Union member states of the OECD and the European Commission: the Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

ANNEX 2.A3

Excerpts from the Protocols Related to Technology Transfer

Helsinki (1985)	The Parties shall reduce their annual sulphur emissions or their transboundary fluxes by at least 30 per cent as soon as possible and at the latest by 1993, using 1980 levels as the basis for calculation of reductions.
Sofia (1988)	The Parties shall, as soon as possible, and as a first step, take effective measures to control and/or reduce their annual emissions of nitrogen oxides or their transboundary fluxes. The Parties shall, as a second step, commence negotiations on further steps to reduce annual emissions […] to this end, the Parties shall co-operate. The Parties shall,…,facilitate the exchange of technology to reduce emissions of nitrogen oxide, particularly through the promotion of: *a)* commercial exchange of available technology; *b)* direct industrial contacts and co-operation, including joint ventures; *c)* exchange of information and experience; and *d)* provision of technical assistance. The Parties shall create favorable conditions by facilitating contacts and co-operation among appropriate organisations.
Oslo (1994)	The Parties shall control and reduce their sulphur emissions in order to protect human health and environment from adverse effects,… and to ensure that depositions… do not exceed critical loads for sulphur given in Annex 1. The Parties shall make use of the most effective measures which includes measures to apply best available control technologies not entailing excessive costs. The Parties shall facilitate the exchange of technologies and techniques, to reduce sulphur emissions, particularly through the promotion of: *a)* commercial exchange of available technology; *b)* direct industrial contacts and co-operation, including joint ventures; *c)* exchange of information and experience; and *d)* provision of technical assistance. The Parties shall create favorable conditions by facilitating contacts and co-operation among appropriate organisations. An Implementation committee is (…) established to review the implementation of the Protocol. The Parties may call for action to bring about full compliance with the present Protocol, including measures to assist a Party's compliance,… and to further the objectives of the Protocol.

Gothenburg (1999)	The objective of the present Protocol is to control and reduce emissions,… and to ensure as far as possible, that in the long term and in a stepwise approach,… atmospheric depositions or concentrations do not exceed… Each Party shall,… create favorable conditions to facilitate the exchange of information, technologies and techniques, with the aim of reducing emissions of sulphur, nitrogen oxides, ammonia and volatile organic compounds by promoting *inter alia*: *a)* the development and updating of databases on best available techniques, including those that increase energy efficiency, low-emissions-burners and good environmental practice in agriculture; *b)* the exchange of information and experience in the development of less polluting transport; *c)* direct industrial contracts and co-operation, including joint ventures; and *d)* the provision of technical assistance. Each Party shall create favorable conditions for the facilitation of contacts and co-operation among appropriate organisations. The Parties shall encourage research, development, monitoring and co-operation related to : the improving of monitoring techniques and systems,… emission abatement technologies, and technologies and techniques to improve energy efficiency, energy conservation and the use of renewable energy.

Source: LRTAP Protocols (*www.unece.org/env/lrtap/status/lrtap_s.htm*).

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