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**ENVIRONMENTAL POLICY FRAMEWORK CONDITIONS, INNOVATION AND TECHNOLOGY  
TRANSFER**

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## FOREWORD

This paper was prepared by Nick Johnstone and Ivan Haščič (OECD Secretariat). It is a contribution to the OECD project on “Environmental Policy and Technological Change”. It focuses on the effects of environmental policy framework conditions on innovation with respect to air and water pollution abatement, and solid waste management.

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## EXECUTIVE SUMMARY

This paper focuses on the issue of innovation and technology transfer in the areas of air pollution abatement, wastewater effluent treatment and solid waste management. The paper describes the trends in innovative activity related to selected areas of pollution abatement and control technologies and their transfer internationally. It also discusses characteristics of environmental policy regimes that are amenable to encouraging innovation of environmental technologies, and provides empirical evidence on the role of various determinants (including general characteristics of countries' environmental policy regimes) in encouraging innovation. Finally, the paper discusses the transfer of environmental technologies and the factors which can affect such transfers and identifies a number of policy implications.

### **What characteristics of environmental policies are likely to induce innovation?**

Rather than assessing the innovation impacts of environmental policies in terms of broad policy 'types' (i.e. market-based instruments vs. direct regulation), it is helpful to think in terms of the more specific characteristics of different instruments, and what effect each of these characteristics has on innovation. The relevant characteristics would include at least the following: stringency, stability (or certainty), flexibility, incidence, and depth. While related, each of these characteristics is distinct and they can be summarised as follows:

- *Stringency* – i.e. how ambitious is the environmental policy target, relative to the 'baseline' trajectory of emissions?
- *Stability* – i.e. what effect does the policy measure have on investor uncertainty; is the signal consistent, foreseeable, and credible?
- *Flexibility* – i.e. does it let the innovator identify the best way to meet the objective (whatever that objective may be)?
- *Incidence* – i.e. does the policy target the externality directly, or is the point of incidence a 'proxy' for the pollutant?
- *Depth* – i.e. are there incentives to innovate throughout the range of potential objectives?

From the perspective of innovation, the ideal policy instrument is one that is: stringent enough to encourage that level of innovation which results in the optimal level of emissions; sufficiently stable to give investors the necessary planning horizon to undertake risky investments in innovation; sufficiently flexible to encourage innovators to identify innovative solutions which have not yet been identified; targeted as closely as possible on the policy objective in order to avoid misallocation of innovation efforts; and, provide continuous incentives to develop abatement technologies which could (in theory) drive down emissions to zero.

### **Why these characteristics may not map directly onto different policy instrument types**

There is good empirical evidence that market-based instruments such as environmentally-related taxes and tradable permits are more likely to induce innovation than direct regulations such as technology-based standards. However, juxtaposing the incentives associated with market-based instruments with direct regulations in broad terms may be misleading since there is no necessary mapping from instrument type to each of the characteristics listed above.

For instance, different environment-related taxes may have very different attributes. A tax on CO<sub>2</sub> is flexible, targeted, deep, and often stable. However, a differentiated value-added tax for ‘environmentally-friendly products’ is not very flexible, targeted or deep. Indeed, depending upon how the tax rate is determined, such a measure may actually have more similarity with technology-based standards than with an emissions tax in terms of impacts on innovation. Similarly, a performance standard may have more similarities with a tax than with a technology-based standard. While it does not provide the same ‘depth’ of incentive – i.e. there is no incentive to innovate in a manner that allows regulated firms to exceed the standard – if it is flexible and targeted, it is likely to have similar innovation impacts to an emissions tax.

The key point is that correlation between instrument types and policy design attributes is imperfect. Any incentives for innovation arise out of the underlying policy characteristics. As such, it is important to assess incentives for innovation in terms of their specific characteristics rather than by broad instrument type. Because of this imperfect correlation, it is necessary to disentangle the innovation effect of each of these characteristics. Drawing upon a worldwide database of patent applications, the effects of three of the most important characteristics (stringency, stability, and flexibility) are examined.

### **Stringent environmental policies provide strong incentives for innovation**

Evidence is presented that policy stringency plays a significant role in inducing innovation. More specifically, based on evidence from a broad cross-section of countries over the period 2000-2007 it is found that policy stringency has a positive impact on the likelihood of developing innovative means of air and water pollution abatement and solid waste management. A more ‘stringent’ policy will provide greater incentives for polluters to search for ways to avoid the costs imposed by the policy.

All ‘environmental’ policies – whether they be taxes, subsidies, regulations, information – attach a price to polluting. By increasing the ‘price’ of polluting, it is hardly surprising to find that the more stringent the policy the greater the effect on innovations which have the effect of reducing emissions. However, this is not to say that different policy measures of equal stringency will not have different effects on the rate and direction of innovation. Policy stringency is only one aspect of the public policy regime which affects the rate of innovation, and it is important to examine some of the other characteristics of policy regimes as well.

### **Uncertain environmental policy conditions add to the risk that investors face in the market, and in doing so serve as a ‘brake’ on innovation**

If there is uncertainty associated with a country’s environmental policy, this will result in less innovation in environmental technologies. Conversely, the more stable and predictable a policy regime, the more innovation is likely to take place. This implies that governments should behave in a predictable manner if they wish to induce innovations that achieve environmental objectives at lower cost. Frequently changing policy conditions come at a cost, and to the extent that these arise out of reasons that are unrelated to new information concerning market or ecological conditions, such instability should be avoided.

Why does this arise? Uncertain signals give investors strong incentives to postpone investments, including the risky investments which lead to innovation. There is an advantage to ‘waiting’ until the policy dust

settles. As such, by adding to the risk which investors face in the market, policy uncertainty can serve as a ‘brake’ on innovation, both in terms of technology invention and adoption. This implies that governments have an interest to behave in a predictable manner if they wish to induce innovations that achieve environmental objectives at lower cost.

However, it must be recognised that in some cases policy instability can arise from the acquisition of information. Damages may be higher or lower than initially foreseen, encouraging the use of more or less stringent policies. Similarly, abatement costs may be higher or lower than initially foreseen. In such cases, there is a trade-off between changing environmental objectives to reflect the new information and keeping incentives constant in order to reduce uncertainty.

### **Flexible environmental policies encourage innovators to search across a wider ‘space’ to identify new ways of complying with regulations**

The third aspect of policy design that is examined empirically in this report is policy flexibility, which can be characterised as technology-neutrality. The results presented indicate that, for a given level of policy stringency, the more ‘inflexible’ a policy regime, the less innovation takes place. In other words, the more ‘flexible’ policy regime will induce more innovation than a regime which is ‘prescriptive’ in nature. This implies that rather than prescribing certain abatement strategies (such as technology-based standards), wherever possible governments should give firms stronger incentives to look for the optimal technological means to meet a given environmental objective.

Since both governments and firms cannot foresee future trajectories of technological change, it is important to give innovators the incentive to search across a wider ‘space’ to identify potential means of complying with regulations. Flexibility ‘unleashes’ the search for new innovations, some of which may be only marginal (but environmentally significant) improvements on existing technologies. Therefore, by encouraging potential innovators to devote resources to identify the best way of achieving a given environmental objective, policy flexibility provides incentives for innovation above and beyond those provided by policy stringency.

### **The stringency and flexibility of environmental policies in both the source and recipient countries encourage international technology transfer**

Environmental policy flexibility also provides incentives for the wide international diffusion of inventions induced. In particular, there appears to be a strong relationship between the flexibility of environmental policy regimes in different countries and the international diffusion of inventions which are first patented in these countries. This highlights the importance of domestic policy design in the realisation of international market opportunities. The effects arise both on the demand side by allowing potential adopters of technology to draw upon the global market, and on the supply side, by encouraging innovators in source countries to develop technologies with wide market appeal.

Conversely, ‘differentiated’ and ‘prescriptive’ technology-based regulations can result in fragmented technology markets, with the potential market for the innovations which are induced restricted to countries in which the regulations are similar. International policy coordination would reduce the potential for such fragmentation. For global public goods (such as mitigation of climate change), such coordination is increasingly evident. However, even in the absence of such coordination, the use of flexible policy instruments at the national level will ensure 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 innovations induced.

## ENVIRONMENTAL POLICY FRAMEWORK CONDITIONS, INNOVATION AND TECHNOLOGY TRANSFER

### 1. Introduction

1. This is one of a series of papers on the subject of environmentally sound technological (EST) innovation. The report expands on initial work previously included in ENV/EPOC/WPNEP(2008)6 and ENV/EPOC/WPNEP(2008)7. This paper focuses on innovation and technology transfer in the areas of air pollution abatement, wastewater effluent treatment and solid waste management, while a companion report [ENV/EPOC/WPNEP(2009)3] focuses on innovation and transfer in the areas of energy use and climate change mitigation.<sup>1</sup> Related work is also focussing on sustainable chemistry and motor vehicle emissions abatement. These reports will serve as the basis for a publication to be issued in 2010.

2. The report first describes the trends in innovative activity related to selected areas of pollution abatement and control technologies, and their transfer internationally. Second, it discusses characteristics of environmental policy regimes that are amenable to encouraging innovation of environmental technologies. It then provides empirical evidence on the role of various determinants (including general characteristics of countries' environmental policy regimes) in encouraging innovation. Third, the paper discusses the transfer of environmental technologies and the factors which can affect such transfers. Fourth, policy implications are discussed.

### 2. Indicators of innovation in general environmental technologies

3. This section describes trends across countries and over time in innovation and international transfer related to selected general environmental technologies (including air pollution control, water pollution control, and solid waste management), using patent data. The data were extracted from the PATSTAT database (EPO 2008) using a search algorithm based on a selection of IPC classes (see the Appendix).<sup>2</sup>

4. Indicators of innovation were constructed based on counts of patent applications (claimed priorities, worldwide) in the selected areas of environmental technology, classified by inventor country (country of residence of the inventor) and priority date (the earliest application date within a given patent family). In order to ensure that only high-value patents are included only applications in which protection has been sought in at least two offices (i.e. 'claimed priorities') are included.<sup>3</sup> A panel of patent counts for a cross-section of all countries and over a time period of 1975-2007 was obtained.

5. Search strategies were developed for different areas, and Figure 1 shows overall patenting activity in the broad environmental domains:

- air pollution abatement from stationary sources;

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<sup>1</sup> For a general discussion of indicators of innovation and transfer using patent data the reader is referred to OECD (2009b). Griliches (1990) is the classic reference. See also OECD (2009a) *Patent Statistics Manual*. And Guellec and Dernis (2001).

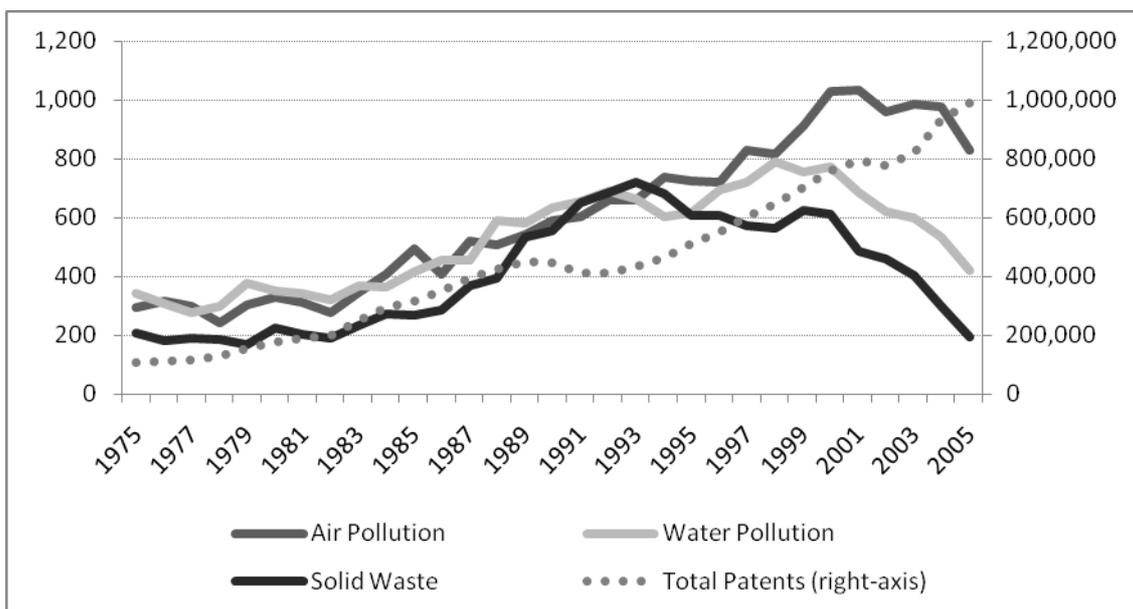
<sup>2</sup> The selection of classifications benefited from searches developed by Lanjouw and Mody (1996) and Schmoch (2003). Assistance of Julie Poirier and Marion Hemar (ENSAE, Paris) in developing the search strategy is equally acknowledged.

<sup>3</sup> See Guellec and van Pottelsberghe (2000) and Harhoff *et al.* (2003) for empirical evidence supporting this approach.

- wastewater effluent treatment; and,
- solid waste management (landfill disposal, recycling, incineration and some aspects of prevention)

6. Overall, these data suggest a recent stagnation in the rate of innovation in these areas. In particular, innovations related to solid waste management reached a peak in 1993 and have declined since. For water pollution control technologies, the peak occurred in the late 1990s. Only air pollution control innovations have been increasing rapidly until very recently, keeping pace with the growth in patenting overall (shown on the right-hand axis).

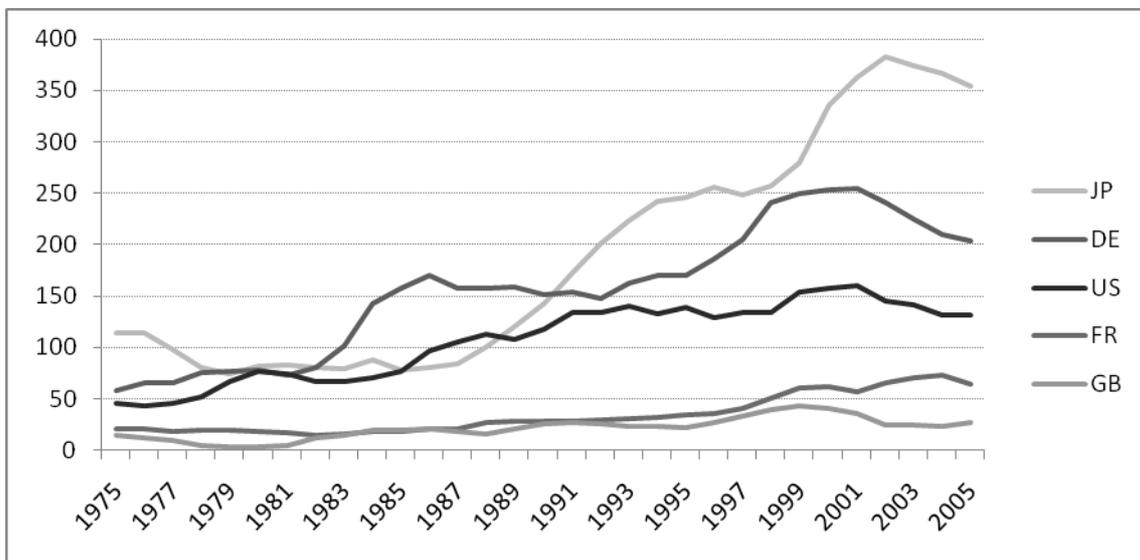
**Figure 1. General 'Environmental' Technologies by Environmental Medium**  
(Number of patent applications - claimed priorities, worldwide)



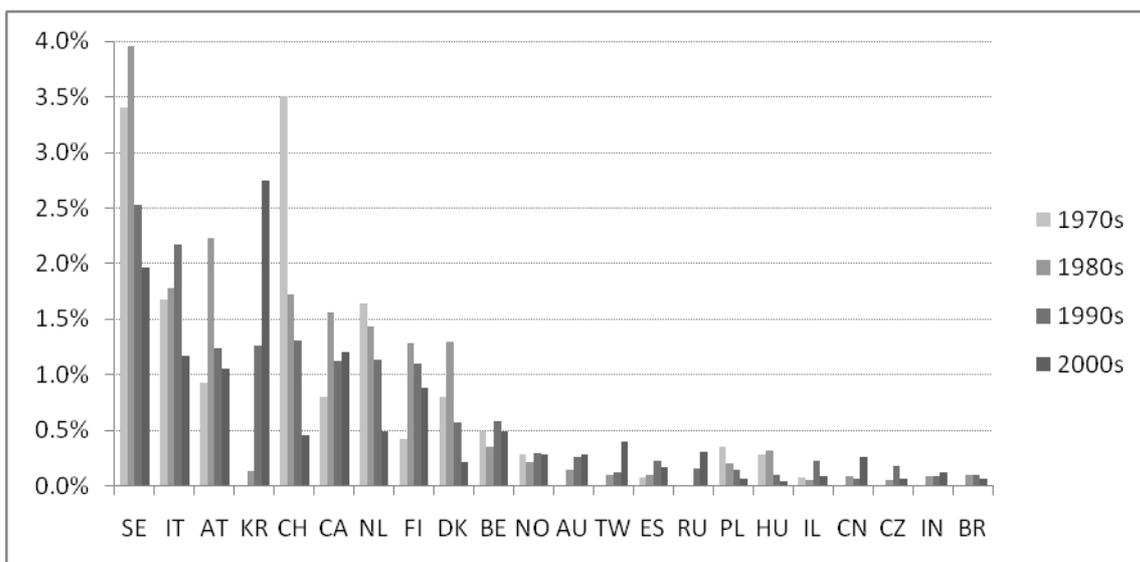
***Air pollution abatement & control***

7. The domain of air pollution abatement & control includes technologies that limit emissions of local air pollutants from stationary sources (e.g., SO<sub>x</sub>, NO<sub>x</sub>, PM). Figure 2 gives patent counts for selected countries with the highest levels of innovation in air pollution abatement, including Germany, Japan, the US, France, and the United Kingdom. While these countries are consistently important in environmental technologies examined, other significant innovators in air pollution control have included Sweden, Italy, Austria, and very recently also Korea (Figure 3).

**Figure 2. Air pollution abatement & control technologies**  
(Number of patent applications - claimed priorities, worldwide; 3-year moving average)



**Figure 3. Air pollution abatement & control technologies**  
(Share on world patenting by inventor country)



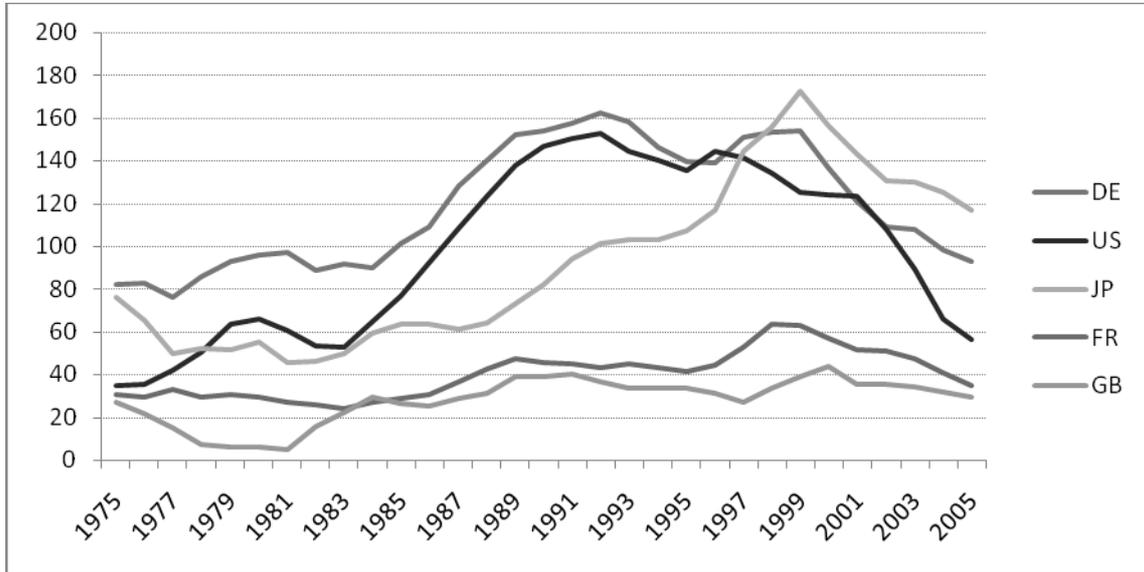
### ***Water pollution abatement and control***

8. The water pollution abatement and control technologies identified here include all wastewater treatment techniques – primary (mechanical), secondary (biological) and tertiary (chemical) treatment technologies.<sup>4</sup> Figure 4 gives patent counts for the five major inventor countries, suggesting that Germany and the US have historically been the major innovators, with Japan taking the lead more recently. Other significant innovators in this field have included Canada, the Netherlands, Sweden, and more recently Korea, Australia and Spain (Figure 5). The rate of growth of this type of innovation in Korea and

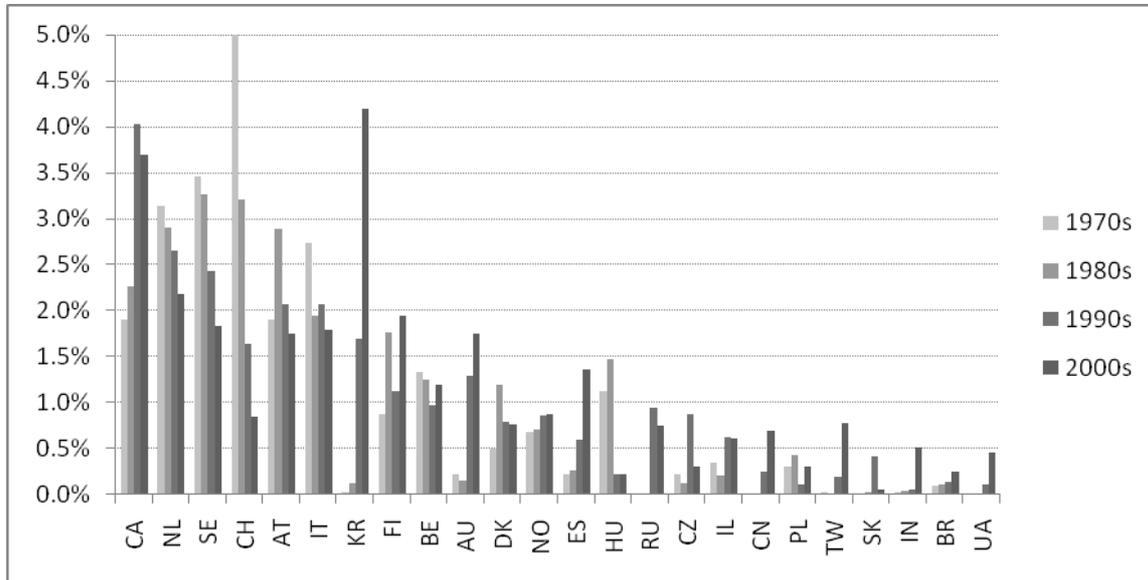
<sup>4</sup> Further work is being undertaken in this project to distinguish more precisely between different types of water and wastewater treatment – including very advanced innovations, such as those involving the application of nanotechnologies.

especially in China in recent years has been startling, increasing four-fold in the period 1999-2004. This is in marked contrast to developments elsewhere, with patent counts for most of the large innovating countries actually decreasing in recent years.

**Figure 4. Water pollution abatement & control technologies**  
(Number of patent applications - claimed priorities, worldwide; 3-year moving average)



**Figure 5. Water pollution abatement & control technologies**  
(Share on world patenting by inventor country)

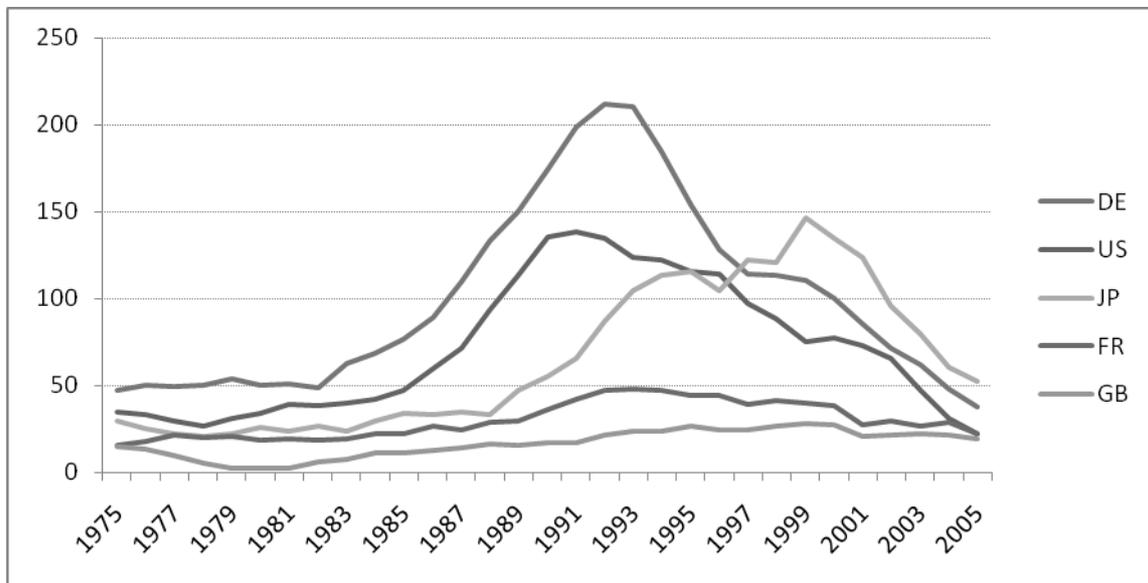


**Solid waste management**

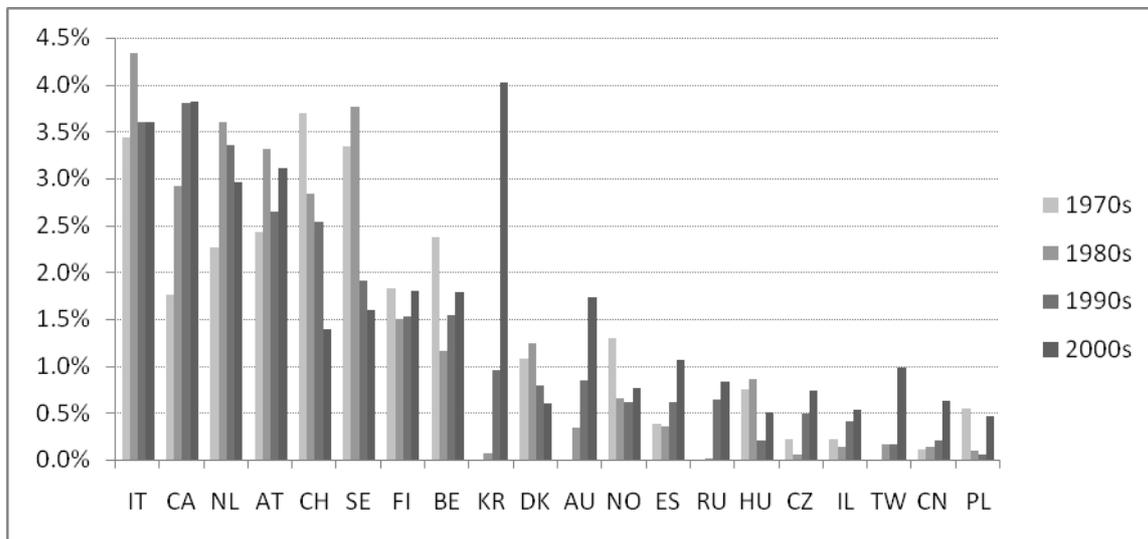
9. The domain of solid waste management included technologies that relate to waste disposal and landfilling, as well as incineration, energy recovery, material recycling and some aspects of waste prevention. As can be seen in Figure 6, there has been a marked decrease in patent activity in this area since a peak in the early 1990s, with German inventors dominating the field throughout the 1980s and 1990s. Among the medium-sized inventor countries (Figure 7), Italy and Canada have sustained a

relatively strong performance. Fast growth rates in the sector have recently been recorded by inventors in Korea, Taiwan, China, and Poland.

**Figure 6. Solid waste management technologies**  
(Number of patent applications - claimed priorities, worldwide; 3-year moving average)

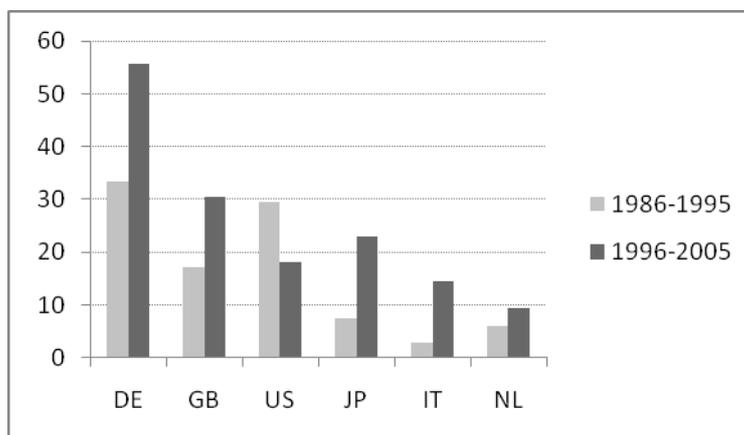


**Figure 7. Solid waste management technologies**  
(Share on world patenting by inventor country)



10. The observed decline in the rate of innovation with respect to solid waste management may be due in part to the difficulty associated with defining search strategies for some aspects of energy recovery, material recycling and waste prevention, which may result in a downward bias in the figures. This is likely to be particularly important in recent years as countries have focussed more of their efforts in these areas. As such, efforts are also underway in this project to develop a more refined set of indicators related to waste management. For instance, in the area of packaging waste, it is possible to identify inventions with respect to “disintegrable and dissolvable packaging materials”. Figure 8 provides some evidence on the main inventor countries in this area, with most countries showing increases in recent years.

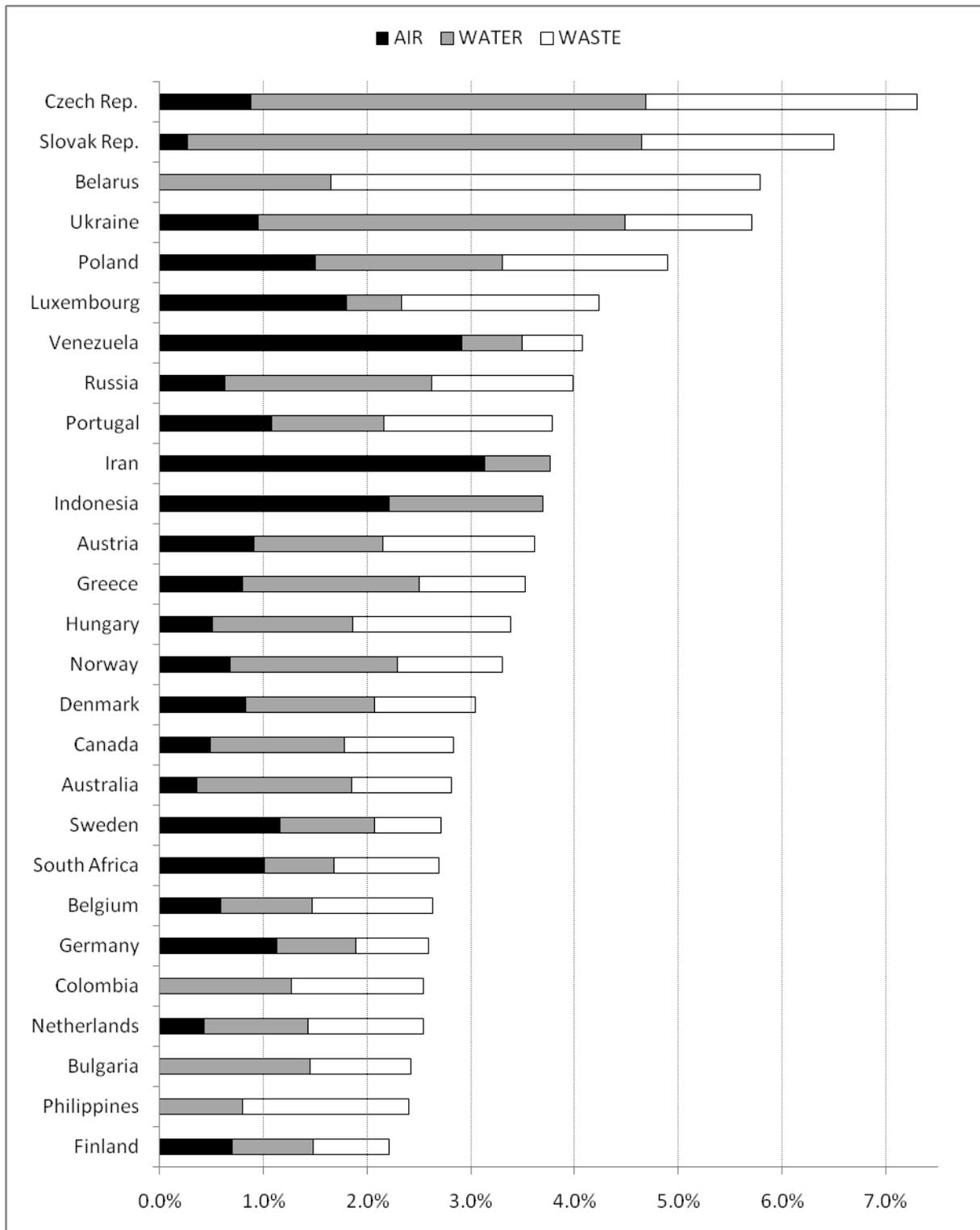
**Figure 8. Packaging Materials – Disintegrable and Dissolvable**  
(Number of patent applications - claimed priorities)

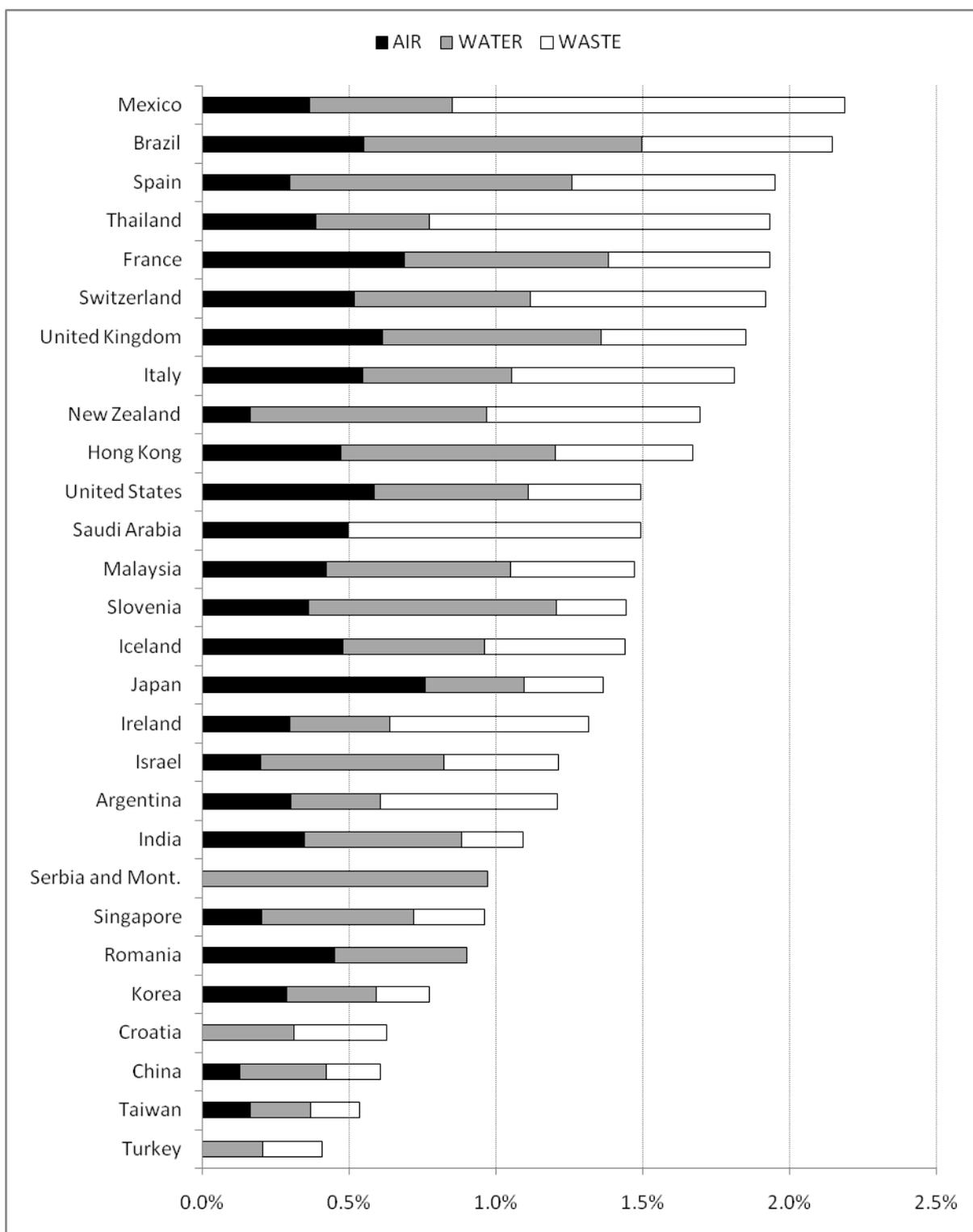


### *Specialisation in AWW technologies*

11. It is also interesting to examine the role of innovations in general environmental technologies in terms of their relative importance in countries' patenting activity overall. Figures 9 and 10 provide information on how 'specialised' countries have been in general 'environmental' technologies over the period 1990-2007. Several factors could play a role here. On the one hand, these figures may reflect a degree of 'catch-up' -- with many countries focusing efforts on areas which have been somewhat neglected in the past (this could explain the high rank of some Central and Eastern European countries). On the other hand, they may also be a function of the weight of relatively more dynamic sectors in a country's innovation portfolio (this could explain the low rank of some fast-growing Asian economies).

**Figure 9. Proportion of Patenting in General 'Environmental' Technologies in Patenting Overall**  
 (Percent Share of Air+Water+Waste in Total Patenting, 1990-2005)





12. Table 1 provides some preliminary information on the main “assignees” (*i.e.* owners of patents) in the three areas. This Table illustrates that invention in air pollution control is relatively more concentrated than in the remaining two sectors, where the most important innovating firms are responsible for less than 1% of patenting. The dominant role of firms from a single country is less evident here. In

addition, firms from multiple industrial sectors are represented, including the manufacturing, chemicals, water supply, and engineering sectors.<sup>5</sup>

**Table 1. Patent Applicants**  
(Percent share of sector total, based on counts of claimed priorities worldwide, 1986-2005)

AIR		WATER		WASTE	
<i>Applicant name</i>	<i>Share</i>	<i>Applicant name</i>	<i>Share</i>	<i>Applicant name</i>	<i>Share</i>
TOYOTA MOTOR CORP	4.031%	SANYO ELECTRIC	0.679%	NIPPON KOKAN KK	0.610%
BOSCH GMBH ROBERT	2.381%	NALCO CHEMICAL	0.667%	BAYER AG	0.511%
NISSAN MOTOR	1.676%	KURITA WATER IND	0.605%	SIEMENS AG	0.440%
EMITEC EMISSIONS	1.463%	BAYER AG	0.473%	MATSUSHITA ELECTRIC	0.411%
NGK INSULATORS LTD	1.356%	EBARA CORP	0.433%	BASF AG	0.404%
DENSO CORP	1.345%	BASF AG	0.394%	METALLGESELLSCHAFT	0.383%
MITSUBISHI HEAVY IND	1.319%	DEGREMONT	0.376%	HITACHI LTD	0.376%
VOLKSWAGEN AG	1.142%	BETZ LABORATOR	0.354%	SANYO ELECTRIC CO	0.376%
DAIMLER CHRYSLER	1.100%	OMNIUM TRAITEME	0.348%	WESTINGHOUSE ELECT	0.340%
SIEMENS AG	0.988%	HITACHI LTD	0.348%	PLASTIC OMNIUM CIE	0.305%
METALLGESELLSCHAFT	0.662%	DEGUSSA	0.342%	CANON KK	0.298%
SANSHIN KOGYO KK	0.657%	HOECHST AG	0.319%	MITSUBISHI HEAVY IND	0.298%
HITACHI LTD	0.609%	SHARP KK	0.308%	KOBE STEEL LTD	0.270%
FORD GLOBAL TECH	0.577%	AHLMANN ACO	0.279%	EBARA CORP	0.262%
MITSUBISHI MOTORS	0.571%	RHONE POULENC	0.274%	ZOELLER KIPPER	0.248%
EBERSPAECHER J	0.545%	ORGANO KK	0.262%	VOEST ALPINE IND ANL	0.248%
FORD GLOBAL TECH	0.529%	HENKEL KGAA	0.262%	TOYOTA MOTOR CORP	0.241%
MAZDA MOTOR	0.518%	FRAUNHOFER GES	0.257%	SONY CORP	0.234%
GEN MOTORS CORP	0.502%	KONISHIROKU	0.251%	VOITH PAPER PATENT	0.227%
MANN & HUMMEL	0.502%	EASTMAN KODAK CO	0.245%	SOLVAY	0.213%
PEUGEOT CITROEN	0.497%	PASSAVANT WERKE	0.228%	HENKEL KGAA	0.213%
BMW AG	0.486%	MITSUBISHI ELECTR	0.211%	HITACHI SHIPBUILDING	0.199%
INST FRANCAIS PETRO	0.475%	LINDE AG	0.200%	FRAUNHOFER GES FOR	0.199%
DONALDSON CO INC	0.470%	ZENON ENVIRONM	0.200%	GEESINK BV	0.184%
FLAEKT AB	0.459%	COMM ENER ATOM	0.194%	INST FRANCAIS PETRO	0.184%
DAIMLER BENZ AG	0.448%	EVAC INT OY	0.183%	COMMISS. EN. ATOM.	0.184%
FORD MOTOR CO	0.443%	PERMELEC ELECT	0.183%	DU PONT	0.184%
YAMAHA MOTOR CO	0.438%	SAMSUNG ELECT	0.177%	KAO CORP	0.177%
ISUZU MOTORS LTD	0.432%	NIPPON CATALYTIC	0.171%	MARTIN UMWELT ENER	0.170%
NIPPON DENSO CO	0.422%	US FILTER CORP	0.171%	GEN ELECTRIC	0.163%
MITSUBISHI ELECTRIC	0.406%	BETZDEARBORN INC	0.165%	HOECHST AG	0.163%
RENAULT	0.400%	BUCKMAN LABOR	0.160%	NIPPON ELECTRIC CO	0.163%

Note: This data is only preliminary. The data on *applicant names* have not been fully harmonized, neither have mergers and acquisitions been taken into account.

<sup>5</sup> The presence of a large number of motor vehicle firms as assignees for air pollution abatement patents indicates that further work needs to be done to distinguish between technologies for stationary and mobile sources.

### 3. Environmental policy framework conditions as a determinant of innovation

13. It has long been recognized that the characteristics of the environmental policy framework (“framework conditions”) can affect the rate and direction of innovation in pollution abatement technologies. This argument is an extension of a more general postulate that public policy may induce innovation by changing relative factor prices or introducing production constraints. The idea was first raised by Hicks (1932), who observed that a change in the relative prices of factors of production will motivate firms to invent new production methods in order to economise the use of a factor which has become relatively expensive. Originally developed in the context of labour economics, this idea came to be known as the “induced innovation hypothesis”. Applied to the public policy framework, it implies that if governments could affect relative input prices, or otherwise change the opportunity costs associated with the use of environmental resources, firms’ incentives to seek improvements in production technology which save on these inputs would be increased. Since markets often fail to put a price on environmental resources, the opportunity costs of many environmental assets is to a large extent formed by government regulation.

14. 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*. However, it is well-known that different policy instruments will affect the incentives for firms to develop and adopt environmentally beneficial technologies in different ways. In general, a strong case has been made for the use of market-based instruments (*e.g.* taxes, tradable permits), rather than direct regulation (*e.g.* technology-based controls, performance standards) in order to induce innovation (see Jaffe *et al.* 2002 and Popp *et al.* 2009 for a review).<sup>6</sup> In particular, it is argued that the rate of innovation under market-based instruments is likely to be greater, since a greater proportion of benefits of technological innovation and adoption will be realised by the firm itself than is the case for many direct forms of regulation. Moreover, since market-based instruments are not usually ‘prescriptive’, they are more likely than many types of direct regulation to ensure that the direction of technological change is cost-minimising with respect to the avoidance of damages.<sup>7</sup> This usual taxonomy is sometimes complemented by review of measures designed to address related (but distinct) market failures, *i.e.* information-based measures, technical assistance, *etc.*

15. However, the stark juxtaposition between market-based instruments and direct forms of regulation is somewhat misleading. It is more helpful to think in terms of vectors of characteristics of different instruments, and what effect each of these characteristics has on innovation. Relevant vectors would include at least the following:

- *Stringency* – *i.e.* how ambitious is the environmental policy target, relative to the ‘baseline’ trajectory?;
- *Stability* – *i.e.* what effect does the policy measure have on investor uncertainty; is the signal consistent, foreseeable, and credible?;
- *Flexibility* – *i.e.* does it let the innovator identify the best way to meet the objective (whatever that objective may be)?;
- *Incidence* – *i.e.* does the policy target directly the externality, or is the point of incidence a ‘proxy’ for the pollutant?; and,

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<sup>6</sup> OECD (2008) assesses the role of six different instrument types on innovation in renewable energy.

<sup>7</sup> See Jaffe *et al.* (2002).

- *Depth* – *i.e.* are there incentives to innovate throughout the range of potential objectives (down to zero emissions)?.

16. There is no precise mapping from instrument type to each of these vectors. For instance, different environment-related taxes may have very different attributes. A tax on CO<sub>2</sub> is flexible, targeted, deep, and often predictable. However, a differentiated tax for ‘environmentally friendly products’ is not very flexible, targeted or deep. Indeed, depending upon how the tax rate is determined, such a measure may actually have more similarity with technology-based standards than with an emissions tax.

17. More generally, a performance standard with a similar point of incidence (*i.e.* on the pollutant itself) and degree of flexibility may have more similarities with a tax than with a technology-based standard. While it does not provide the same ‘depth’ of incentive – *i.e.* there is no incentive to go beyond the standard<sup>8</sup> – in other respects it is likely to have similar innovation impacts as an emissions tax.

18. The key point is that correlation between instrument types and policy design attributes is imperfect. Any incentives for innovation arise out of the underlying policy attributes. As such, it is important to assess incentives for innovation in terms of the attributes rather than by broad instrument type. Because of this imperfect correlation, it is necessary to disentangle the distinct effect of each of these attributes empirically. In the remainder of this Section, the effects of the different attributes are discussed in more detail and assessed empirically. Due to data constraints, only the first three attributes (stringency, flexibility and stability) are assessed empirically.

19. Drawing upon the PATSTAT database of patent applications, we argue that the different types of environmental policy regimes have an important and distinct role in encouraging innovation. The principal hypotheses to be examined are:

- H<sub>1</sub>: Policy stringency has an effect on invention.
- H<sub>2</sub>: Policy stability has an effect on invention above and beyond that of stringency.
- H<sub>3</sub>: Policy flexibility has an effect on invention above and beyond that of stringency.

20. An empirical model is developed to test the hypotheses. The following reduced-form equation is specified and estimated for stringency, stability, and flexibility as policy design attributes:

$$AWWPAT_{i,t} = \beta_1 ENVPOLICY_{i,t} + \beta_2 TOTPAT_{i,t} + \varepsilon_{i,t}$$

where *i* indexes country and *t* indexes year. The dependent variable is measured by the number of patent applications in selected areas of environmental technology – air, water, and waste (AWW) – which was described above. ENVPOLICY accounts for the different attributes of countries’ environmental policy regimes. This data is obtained from the *World Economic Forum’s* “Executive Opinion Survey”, which asked respondents a number of questions related to environmental policy design. The survey was implemented by the WEF’s partner institutes in over 100 countries, which include departments of economics at leading universities and research departments of business associations. The means of survey implementation varied by country and included postal, telephone, internet and face-to-face survey. In most years, there were responses from between 8,000 and 10,000 firms (see WEF 2008 for a description of the sampling strategy.)

21. Aside from environmental policy, there are, of course, other important determinants of patenting activity for environmentally preferable technologies. This includes the propensity to invent technologies, in

<sup>8</sup> Unless it is assumed that the standard itself will change as a consequence. See Milliman and Prince (1989).

general, and the propensity to obtain any investor protection through existing intellectual property rights (IPR) regimes. Factors such as general scientific capacity, market conditions, openness to trade, *etc.* will also have an important effect on patenting activity, in general, and thus also in the specific field of environmental technologies. The propensity of inventors from a particular country to patent is likely to change over time, both because different strategies may be adopted to capture the rents from innovation (*e.g.*, Cohen *et al.* 2000) and because legal conditions may change through time (*e.g.*, Ginarte and Park 1997). In addition, it is important to control statistically for differences in the propensity to patent across countries. In order to capture the effect of such factors (which are not specific to environmental technologies), we include the variable TOTPAT reflecting the total number of patent applications (claimed priorities) filed across the whole spectrum of technological fields (not only environmental). This variable thus serves both as a ‘scale’ and as a ‘trend’ variable in that it controls for differences in the effects of the size of a country’s research capacity on innovation as well as changes in general propensity to patent over time and across countries. All the residual variation is captured by the error term ( $\varepsilon_{i,t}$ ). A negative binomial model is used to estimate the model.

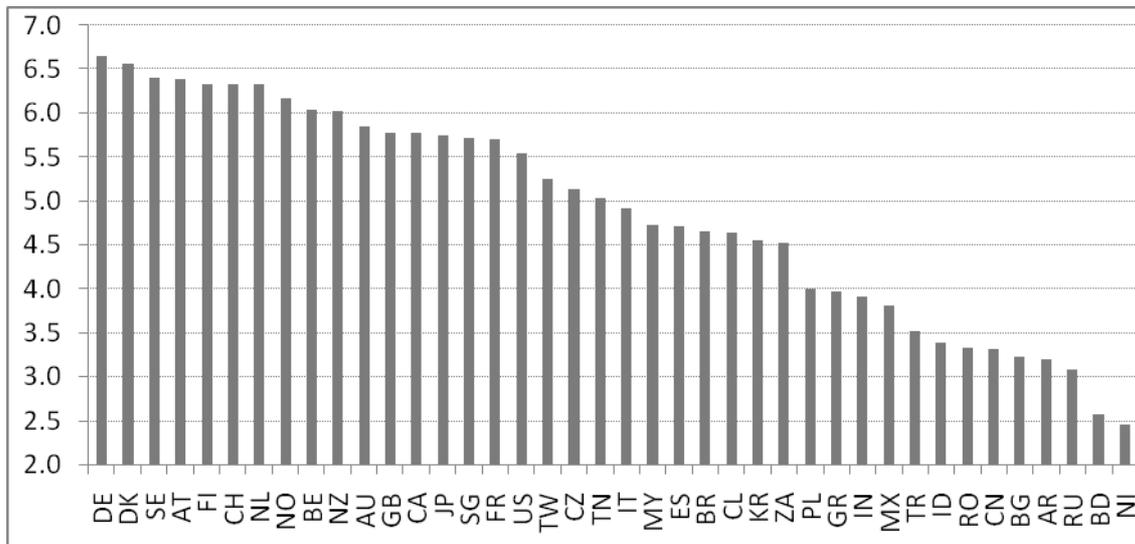
### **3.1. Environmental policy stringency**

22. While theoretical work has shown that environmental regulation may provide incentives for technological improvements, empirical evidence on the effect of stringency of environmental policy on innovative behaviour remains limited (for recent reviews of the empirical literature on this theme see Popp *et al.* 2009; Vollebergh 2007; Jaffe *et al.* 2002). The major reason is that this effect is unobservable to a researcher; hence, its measurement is complicated. As a consequence, cross-country (or cross-sectoral) data on regulatory stringency are rarely available, or are not commensurable. Moreover, public policies typically target specific environmental impacts (pollutants) using a specific policy instrument.

23. A number of imperfect proxies have been used in the literature. This includes reported data on pollution abatement and control expenditure measured at the macroeconomic (*e.g.*, Lanjouw and Mody 1996) or sectoral level (*e.g.*, Brunnermeier and Cohen 2003), the frequency of inspection visits (*e.g.*, Jaffe and Palmer 1997), parameterisation of policy types (*e.g.*, Fischer and Newell 2008), or various derived measures based on the point of policy implementation (*e.g.*, Johnstone *et al.* 2008 and Johnstone and Labonne 2006).

24. 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 stringency of environmental policy regimes. However, in the WEF survey, respondents (usually CEOs) were requested to indicate the “stringency” of a country’s overall environmental regulation. More specifically, they were requested to assess the degree of stringency on a Likert scale, with 1 = lax compared with that of most other countries, 7 = among the world’s most stringent. Mean responses for 40 selected countries from our sample are provided in Figure 10.

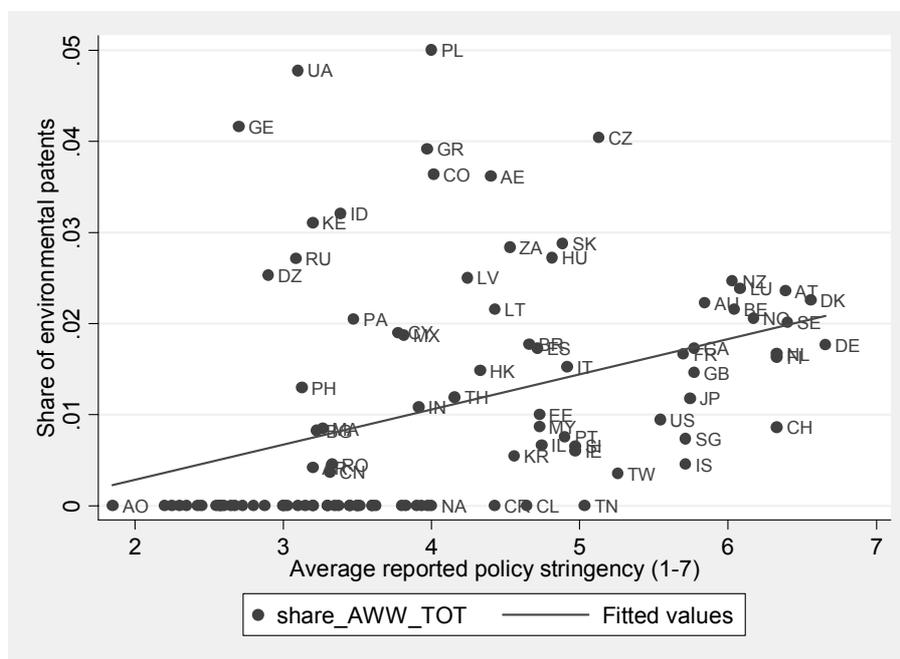
**Figure 10. Stringency of Environmental Policy Regimes in Selected Countries**  
(Mean value of the index over 2001-2007)



Survey question: Environmental policies in your country are 1 = lax compared with that of most of other countries, 7 = among the world's most stringent. Source of data: <http://www.weforum.org/en/initiatives/gcp/index.htm>.

25. In this sub-section we test our first principal hypothesis about the relationship between policy stringency and innovation by using the WEF index described above. Figure 11 shows a scatter plot of the stringency of environmental policy regimes (mean responses for the period 2001-2007 for 102 OECD and non-OECD countries for which the WEF data is available) and of innovations which relate to environmental technologies (the share of 'environmental' patents over total patents, shown as mean values for the same time period). The plot suggests a positive linear relationship (Pearson correlation coefficient is 0.37).

**Figure 11. Stringency of Environmental Policy Regimes and Innovation of Environmental Technologies (2001-2007)**



26. Table 2 reports the results from the estimation of the reduced-form model of environmental innovation presented above on the WEF index of policy stringency for 77 countries over the period 2001-2007. Hardly surprisingly, the estimate of STRING is always positive and significant no matter whether we include time fixed effects or not. This result confirms previous evidence (*e.g.* Lanjouw and Mody 1996 and Brunnermeier and Cohen 2003).

**Table 2. Policy Stringency and Environmental Patents (2001-2007)**

Dependent variable: AWWPAT		
	(1)	with year fixed effects (2)
Stringency of Env Policy (STRING)	0.791*** (0.071)	0.850*** (0.069)
Total Patents (TOTPAT)	0.204*** (0.026)	0.191*** (0.023)
Intercept	-2.580*** (0.334)	-2.411*** (0.432)
N	440	440
Log pseudolikelihood	-1104.36	-1083.09
(Prob>Chi2)	0.000	0.000

Standard errors in parentheses, \* p<0.05, \*\* p<0.01, \*\*\* p<0.001.

27. Next, we estimate the model using a two-stage procedure of the form  $AWWPAT = f(ENVPOLICY, TOTPAT)$ , where total patenting activity is first estimated as  $TOTPAT = g(\text{economic size, scientific capacity, rule of law, openness, etc.})$ . In Table 3 we present the results from the first-stage regression of total patents (TOTPAT) on lagged gross domestic product ( $GDP_{(-1)}$ ) and an index of the strength of property rights protection ( $IPR_{(-1)}$ ), gross domestic expenditure on R&D (GERD) as a percentage of GDP, and net international trade value. The equation is estimated as an unconditional negative binomial fixed effects model. The results are in line with previous work on general innovative activity, including that undertaken in the Economics Department of the OECD (see Jaumotte and Pain 2005).

**Table 3. Determinants of Total Patents (2001-2007)**

Dependent variable: TOTPAT	
GDP	0.711*** (0.066)
Gross Domestic Expenditures on R&D	0.681*** (0.139)
IPR protection	1.614*** (0.186)
Net International Trade	0.076*** (0.011)
Intercept	-2.161** (0.683)
N	191
Log pseudolikelihood	-1452.89
(Prob>Chi2)	0.000

Standard errors in parentheses, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

28. From the estimation above we calculate the fitted values of total patents and use them as an explanatory variable, instead of TOTPAT, in the second-stage of the regression on AWWPAT. In Table 4 we compare the results with the predicted values of total patents (columns 1 and 3) and the TOTPAT variable (columns 2 and 4) as regressors. Although the coefficient of the predicted total patents is smaller in magnitude, the expected positive sign and statistical significance persist. The findings suggest that an estimation of the reduced-form model, where total patents are considered to be exogenous, provides closely comparable results with those of the two-stage estimation and thus justify the use of the reduced-form model in the subsequent econometric analyses.

**Table 4. Second-Stage Regression of Environmental Innovation on Stringency**

Dependent variable: AWWPAT	with time FEs			
	Predicted total patents	Total patents	Predicted total patents	Total patents
	(1)	(2)	(3)	(4)
Stringency of Env Policy (STRING)	0.803*** (0.102)	0.506*** (0.087)	0.815*** (0.097)	0.529*** (0.083)
Total Patents (TOTPAT)		0.134*** (0.015)		0.128*** (0.014)
Predicted Total Patents	0.067*** (0.011)		0.071*** (0.010)	
Constant	-1.564** (0.544)	-0.465 (0.460)	-1.275* (0.565)	-0.271 (0.479)
N	191	191	191	191
Log Pseudolikelihood (Prob>Chi2)	-754.68 0.000	-714.21 0.000	-733.00 0.000	-699.94 0.000

Standard errors in parentheses, \* p<0.05, \*\* p<0.01, \*\*\* p<0.001.

29. By imposing a price (whether explicitly or implicitly) on the costs of pollution emissions, or by otherwise changing the opportunity costs associated with environmental assets, environmental policy is likely to induce innovation -- because firms seek to meet the policy objectives at least cost. Of course, different policy measures may be more or less likely to induce innovation. Irrespective of the nature of the instrument applied, some innovation is likely to be induced. However, as argued previously, policy stringency is only one aspect of the public policy regime which affects the rate of innovation. Other potentially important aspects are discussed next.

### 3.2. Environmental policy certainty

30. It is well-known that economic uncertainty can be a significant “brake” on investment (see Pindyck 2007; Dixit and Pindyck 1994). However, this may be particularly true of investments in R&D, which are by nature risky and with uncertain outcomes. This is compounded by the fact that such investments are irreversible; should market conditions change, “sunk costs” cannot be recovered in the market. Both characteristics (uncertainty and irreversibility) thus give rise to a commercial risk associated with innovative activities. Investment in R&D is therefore often sub-optimal. For instance, in a panel data study of nine OECD countries covering the period 1981–1992, Goel and Ram (2001) find a much sharper adverse effect of uncertainty on R&D investments than on non-R&D (and aggregate) investments.

31. In the case of ‘environmental’ innovations, this market uncertainty can be compounded by environmental policy uncertainty. This may arise due to concerns over the ‘stability’ of the policy framework, as well as of the signals provided by the policy itself. In such cases, uncertain signals and ‘irreversible’ investments give rise to great option values, implying strong incentives to postpone investments.<sup>9</sup> Recent work at the IEA (2007) has examined this issue in the context of climate policy uncertainty.

<sup>9</sup> In the environmental context, irreversibilities are partly a function of the nature of investments – *i.e.* end-of-pipe abatement vs. change-in-production processes.

32. As such, it might be supposed that governments which do not provide clear signals about policy intentions over the duration of firms' planning horizons will retard investment in innovation. In particular, if the future trajectory of the costs associated with policies is uncertain, individual firms may choose to wait before undertaking investments which seek to identify means of reducing this cost (*i.e.* before investing in environmental R&D). Since expectations concerning the path of future environmental policy can be a key determinant of perceived uncertainty over the firm's planning horizon, policy 'stability' can play an important role in inducing environmental innovation, and one which is distinct from that played by policy 'stringency'.

33. However, the effect of policy uncertainty on innovation with respect to environmental technologies has not been examined empirically. (For a recent paper which looks at the role of policy uncertainty on abatement investment decisions, rather than innovation *per se*, see Lofgren *et al.* 2008.) However, there is significant anecdotal evidence in the area of renewable power development to support the hypothesis that policy stability has played at least as important a role as policy stringency (see Soderholm *et al.* 2007, Wiser and Pickle 1998, Barradale 2008). For instance, Barradale (2008) argues that in the case of the United States, uncertainty concerning the annual renewal of the federal production tax credit (PTC), discouraged investment in renewable energy. This finding is supported by anecdotal evidence presented in Wiser and Pickle (1998) concerning both wind and solar power. In a comparison of wind power development in Denmark, Germany and Sweden, Soderholm *et al.* (2005) argue that the relatively slow pace of development in Sweden is due to instability in the policy framework, more than the actual level of support, with a number of different subsidy programmes implemented successively for short periods of time.

34. The effects of frequent policy changes on long-term investments can, therefore, be considerable. Since the planning horizon for investments in innovation is particularly long, such investments are likely to be significantly affected by policy instability. A history of abrupt policy changes can discourage investment, and this is likely to be exacerbated by the perception that such instability is likely to continue. Interestingly, Barradale (2008) provides evidence that perceived uncertainty is correlated with instrument choice. Investors in the sector believed that renewable energy portfolio standards were more likely to stay in effect long enough to influence long-term investment decisions than depreciation rules, tax credits, feed-in tariffs or production subsidies. Table 5 gives a possible classification of different policy instrument types according to the uncertainty of the signals they typically provide.

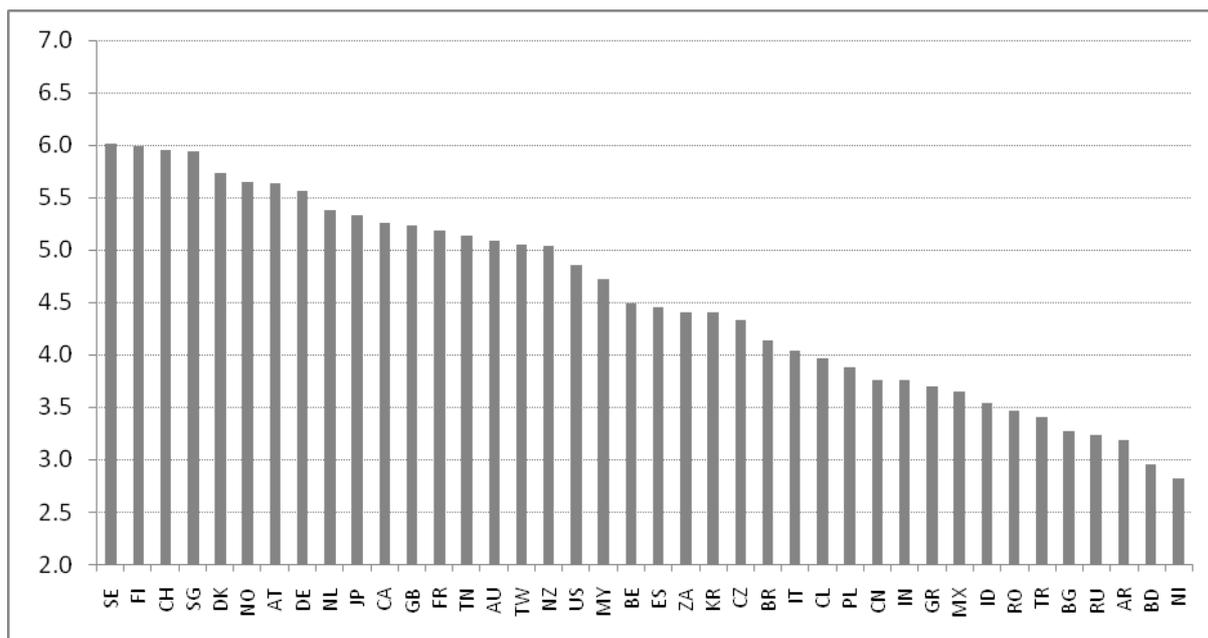
**Table 5. Policy Instrument Types and Uncertainty**

<i>Instrument type</i>	<i>Uncertainty of signals provided</i>
Taxes	Certain price signals – assuming that taxes are set at a level which investors see as being sustainable and credible
Subsidies	Relatively certain price signals – but credibility may be more of a concern (public finance)
Permits	Uncertain price signals – but (assuming no expropriation) equivalent to commercial risk for investors
Performance-based standards	Essentially analogous to permits – but greater bureaucratic discretion can introduce uncertainty
Technology-based standards	Certainty at a point in time – but problem of 'ratcheting' ( <i>e.g.</i> new source bias)

35. To test the second principal hypothesis (concerning the relationship between policy stability and environmental innovation), we need an appropriate measure of policy stability. 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 'stability' of environmental policy regimes. However, for 2001-2006, the WEF survey also asked respondents about their perceptions of the

“stability and clarity” of the environmental policy regime in different countries. Respondents were requested to indicate on a Likert scale whether environmental regulations were “confusing and frequently changing” (1) or “transparent and stable” (7). They were invited to provide responses for all countries in which their firm was present. Mean responses for selected countries are provided in Figure 12. The Nordic and Alpine countries would appear to have the most ‘stable’ regimes, with some G7 countries (e.g. Italy) recording rather low scores.

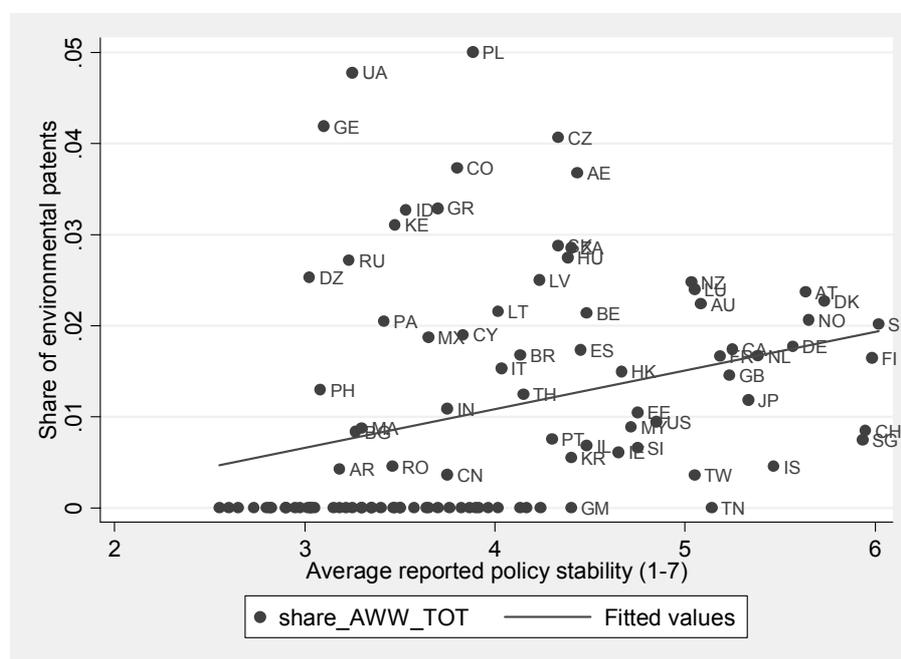
**Figure 12. Stability and Transparency of Environmental Policy Regimes**  
(Mean value of the index over 2001-2006)



Survey question: Environmental policies in your country are 1 = confusing and frequently changing, 7 = transparent and stable.  
Source of data: <http://www.weforum.org/en/initiatives/gcp/index.htm>.

36. Figure 13 presents a scatter plot of the relationship between the index of the stability of environmental policy regimes (mean responses for the period 2001-2006 for 102 OECD and non-OECD countries for which the WEF data is available) and of innovations which relate to environmental technologies (the share of ‘environmental’ patents over total patents, shown as mean values for the same time period). The correlation is 0.30.

**Figure 13. Stability and Clarity of Environmental Policy Regimes and Innovation of Environmental Technologies (2001-2006)**



37. As noted above, there are a number of factors (other than policy stability) which affect an individual country's innovative activity with respect to the environment. Firstly and most significantly, as has been reported, policy stringency is likely to play a role. However, the two measures of environmental policy (stability and stringency) are highly correlated (0.90) which will lead to multi-collinearity if we consider them jointly in the regression. To deal with this potential problem we use factor analysis to construct a variable which is a linear combination of the two correlated environmental policy measures plus an error term.<sup>10</sup> In the empirical analysis *FACTOR* accounts for the joint impact of (un)certainty of the policy conditions and stringency of environmental regulations on innovative activity with respect to environmental technologies. It will be possible to extract the individual effect of policy stability by comparing the coefficient estimates of *FACTOR* with that of *STRING*. Descriptive statistics for the estimation sample of 77 countries over the period 2001-2006 are provided in Table 6.

**Table 6. Descriptive Statistics (2001-2006)**

Variable	Unit	Obs	Mean	Std.dev.	Min	Max
AWWPAT	Count	386	26.423	86.191	0	622
STRING	Index	386	4.554	1.254	1.200	6.800
STAB	Index	386	4.320	0.939	1.600	6.700
FACTOR	Normalized	386	0.000	0.955	-2.720	1.995
TOTPAT	Count	386	2111.30	6863.44	0	49263

<sup>10</sup> The newly created variable (*FACTOR*) is normally distributed with a mean of 0 and variance of 1 and contains equal shares of the stringency and stability indexes.

38. Table 7 reports the empirical results. Models (1a) and (1b) consider the effect of environmental policy stability over the whole sample in a pooled estimation, while models (2a) and (2b) include year fixed effects. The estimate of FACTOR is positive and highly significant in all specifications estimated. The coefficient on the STRING variable is also positive and significant. Most importantly, the FACTOR coefficient is always larger than the measure of policy stringency. These results indicate that policy stability has a positive and statistically significant impact on inventive activity in ‘environmental’ technologies (air, water, waste) that is distinct from, and additional to, the effect of stringency. The coefficient on the TOTPAT variable is positive and highly significant suggesting that patenting activity in the selected ‘environmental’ technologies is also explained by variation across countries and over time in patenting activity overall.

**Table 7. Regression Results: Policy Stability and Innovation (2001-2006)**

Dependent variable: AWWPAT				
	(1a)	(1b)	(2a)	(2b)
Stringency of Env Policy (STRING)	0.814*** (0.075)		0.838*** (0.072)	
Factor of Env Policy (FACTOR)		1.061*** (0.104)		1.089*** (0.097)
Total Patents (TOTPAT)	0.181*** (0.030)	0.182*** (0.029)	0.185*** (0.029)	0.184*** (0.028)
Intercept	-2.528*** (0.394)	1.202*** (0.107)	-2.328*** (0.450)	1.560*** (0.230)
Time fixed effects	No	No	Yes	Yes
N	386	386	386	386
Log pseudolikelihood	-1027.52	-1031.70	-1019.50	-1023.57
(Prob>Chi2)	0.000	0.000	0.000	0.000

Robust standard errors in parentheses, \* p<0.05, \*\* p<0.01, \*\*\* p<0.001

39. To conclude, these results indicate that policy stability has a positive and statistically significant impact on inventive activity in ‘environmental’ technologies (air, water, waste) that is distinct from the effect of stringency. This empirical evidence supports the hypothesis that environmental policy uncertainty can result in less innovation in environmental technologies. The more ‘unstable’ a policy regime, the less innovation takes place. This implies that governments have strong incentives to behave in a predictable manner if they wish to induce innovations which achieve environmental objectives at lower cost. Frequently changing policy conditions come at a cost, and to the extent that these arise out of reasons which are unrelated to changing market or ecological conditions, such instability should be avoided.

40. However, it must be recognised that in some cases policy instability can arise from the acquisition of information. Damages may be higher or lower than initially foreseen, encouraging the use of more or less stringent policies.<sup>11</sup> Similarly, abatement costs may be higher or lower than initially foreseen.<sup>12</sup> This uncertainty can persist for some time, with new information sometimes running counter to

<sup>11</sup> See Baker and Adu-Bonnah (2008) for a discussion in the context of climate change.

<sup>12</sup> See Burtraw and Palmer 2004 for a review.

previous findings. In such cases, there is a trade-off between changing environmental objectives to reflect the new information and keeping incentives constant in order to reduce uncertainty. Further theoretical and empirical work is needed to assess this trade-off.

### **3.3. Environmental policy flexibility**

41. The role of the flexibility of environmental policy measures on innovation has also not been examined closely. In this section we assess whether flexible policies induce innovation. The hypothesis is that if more ‘prescriptive’ policies are applied, technology invention and adoption decisions are constrained by the precise characteristics of the standard. Thus, in order to induce search for the optimal technology to meet a given environmental objective governments should seek to allow for more flexibility in their policy regimes when this can be achieved at reasonable administrative cost.

42. The most prominent example of a flexible environmental policy is the US Clean Air Act Amendments (CAAA) of 1990 which sought to reduce SO<sub>2</sub> emissions by implementing a tradable permit system. The programme was designed to encourage the electricity industry to minimize the cost of reducing emissions. The industry is allocated a fixed number of total allowances, and the firms are required to surrender one allowance for each ton of sulphur dioxide emitted by their plants. Firms may transfer allowances among facilities or to other firms, or bank them for use in future years.

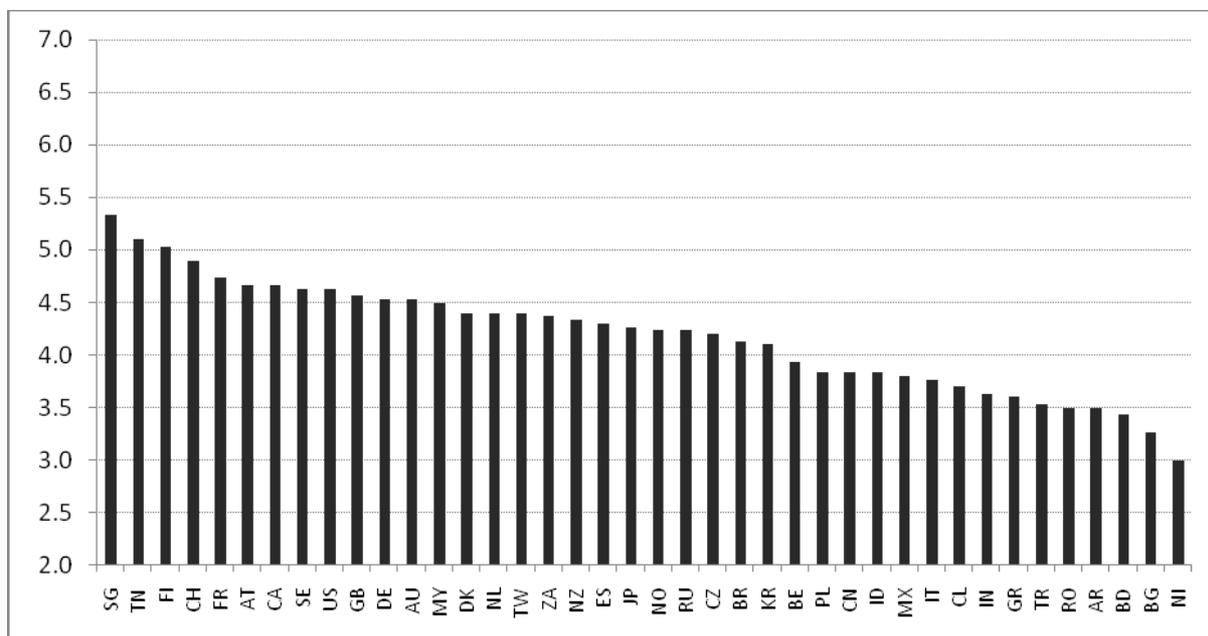
43. However, prior to the CAAA, plants were required to use the best available technology for pollution control, which was a scrubber. As a result, while there were incentives for innovation that would lower the cost of installing and operating scrubbers, there would be little incentives for innovation to improve the efficiency of the scrubbers (that is, ability to actually remove pollutants) (see Bellas 1998.) Moreover, the most significant benefits of the trading system was that it gave firms the freedom to search for all possible technologies to reduce SO<sub>2</sub> emissions (see Burtraw 2000).

44. As an alternative example, consider the NO<sub>x</sub> charge in Sweden. The introduction of a rather stringent tax on NO<sub>x</sub> emissions, supported by close monitoring, created a strong incentive for polluting firms to search for abatement options. Most significantly, the tax induced abatement over a wide range of responses, including fuel switching, modifications to combustion engineering, installation of specific abatement equipment such as catalytic converters and selective noncatalytic reduction, as well as fine-tuning combustion and other processes to minimize emissions (for more detail on the Swedish NO<sub>x</sub> charge, see Millock and Sterner 2004).

45. Both of these examples relate to market-based instruments: tradable permits; and, environmentally-related charges. However, it is important not to conflate market-based instruments with policy flexibility and direct regulations with inflexibility. Some market-based instruments can be prescriptive (*e.g.* differentiated value-added taxes based upon technical criteria of the product) and some direct forms of regulation can be flexible (*e.g.* performance standards in which the point of incidence is the pollutant itself). In such cases the direct regulation may well provide greater space for potential technologies than a market-based instrument, thus inducing more innovation.

46. Therefore, in order to test our third principal hypothesis (about the relationship between policy flexibility and environmental innovation) we use the flexibility index from the WEF survey over the period 2001-2003. In particular, 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. Mean responses for some of the countries included in the sample discussed here are provided in Figure 14.

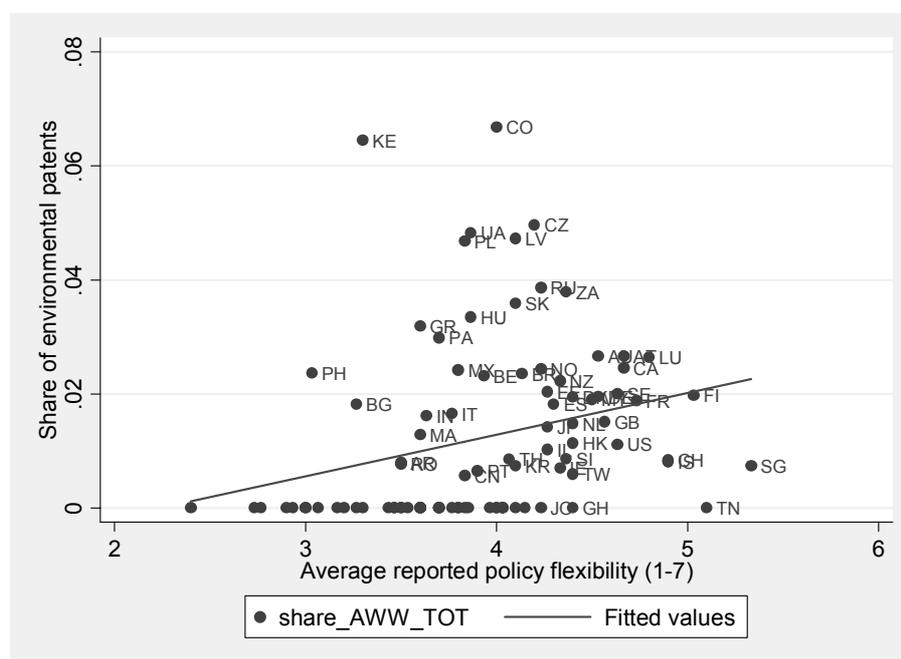
**Figure 14. Flexibility of Environmental Policy Regimes**  
(Mean value of the index over 2001-2003)



Survey question: Environmental policies in your country are with 1 = offer no options for achieving compliance, 7 = are flexible and offer many options for achieving compliance. Source of data: <http://www.weforum.org/en/initiatives/qcp/index.htm>.

47. Figure 15 shows a scatter plot of the relationship between the index of flexibility of environmental policy regimes (mean responses for the period 2001-2003 for 95 OECD and non-OECD countries for which the WEF data is available) and of innovations which relate to environmental technologies (the share of 'environmental' patents over total patents, shown as mean values for the same time period). The data suggest a positive relationship (correlation is 0.27).

**Figure 15. Flexibility of Environmental Policy Regimes and Innovation of Environmental Technologies (2001-2003)**



48. As discussed above, there are a number of other factors that may affect an individual country's innovative activity with respect to the environment. Most importantly – evidence presented above indicates that policy stringency plays a role. However, as with the case of policy stability since the two measures characterizing environmental policy (flexibility and stringency) are highly correlated (0.80), considering them jointly in a regression may lead to multi-collinearity. We tackle the potential problem in a similar way to the previous sub-section by applying the method of factor analysis. In the empirical analysis *FACTOR* will account for the joint impact of flexibility of the policy conditions and stringency of environmental regulations on innovative activity with respect to environmental technologies. It will be possible to identify the individual effect of policy flexibility by comparing the coefficient estimates of *FACTOR* with the one of *STRING*. Descriptive statistics for the estimation sample of 73 countries over the period 2001-2003 are provided in Table 8.

**Table 8. Descriptive statistics (2001-2003)**

Variable	Unit	Obs	Mean	Std.	Min	Max
AWWPAT	Count	204	29.438	94.218	0	622
FLEX	Index	204	4.016	0.608	1.700	5.400
STRING	Index	204	4.388	1.314	1.200	6.700
FACTOR	Normalized	204	0.000	0.871	-2.895	1.804
TOTPAT	Count	204	1991.419	6542.097	0	41904

49. Table 9 reports the empirical results. Models (1a) and (1b) consider the effect of environmental policy regime over the whole sample in a pooled estimation, while models (2a) and (2b) include year fixed effects. In order to pick up the distinct effect of environmental policy flexibility on innovation we compare the coefficients of *FACTOR* and *STRING*. The estimate of *FACTOR* is positive and highly significant in all model specifications estimated. The coefficient of the *STRING* variable is also positive and significant. Most importantly, the coefficient of *FACTOR* is always larger than that of *STRING* policy stringency.

These results clearly indicate that policy flexibility has a positive and statistically significant impact on inventive activity in environmental technologies (air, water, waste) that is distinct from, and additional to, the effect of policy stringency. The coefficient of the TOTPAT variable is positive and highly significant suggesting that patenting activity in the selected environmental technologies is also explained by variation in total patenting activity across countries and over time.

**Table 9. Regression Results: Policy Flexibility and Innovation**

Dependent variable: AWWPAT_it	(1a)	(1b)	(2a)	(2b)
Policy Stringency (STRING_it)	0.891*** (0.102)		0.891*** (0.101)	
Factor of Policy (FACTOR_it)		1.506*** (0.150)		1.534*** (0.152)
Total Patents (TOTPAT_it)	0.163*** (0.039)	0.169*** (0.042)	0.163*** (0.039)	0.164*** (0.038)
Intercept	-2.626*** (0.543)	1.255*** (0.138)	-2.529*** (0.582)	1.435*** (0.211)
Year fixed effects	No	No	Yes	Yes
N	204	204	204	204
Log Pseudolikelihood (Prob>Chi2)	-557.05 0.000	-556.41 0.000	-556.83 0.000	-552.83 0.000

Robust standard errors in parentheses, \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

50. To conclude, empirical evidence has been presented which supports the hypothesis that increased flexibility of environmental policy can result in greater innovation in environmental technologies. For a given level of policy stringency, the more „inflexible“ a policy regime, the less innovation takes place. This implies that rather than prescribing certain abatement strategies (such as technology-based standards), governments should give firms stronger incentives to look for the optimal technological means to meet a given environmental objective. This is important because if firms are allowed to search across a wider „space“ to identify the means of complying with regulations, the objectives of environmental policy will be met at lower cost. Moreover, such issues are of relevance in other policy spheres. For instance, both Gann *et al.* (1998) and Oster and Quigley (1977) discuss the case of effect of building codes and standards on technological innovation.

### 3.4. Environmental policy depth

51. The ‘depth’ of a policy refers to the range of environmental outcomes for which incentives for further environmental improvements are provided. In general, a policy which is continuous in nature is ‘deep’, while one which is discrete will be ‘shallow’. A policy is ‘deep’ if there are opportunity costs associated with emitting pollutants across the entire feasible range of emissions (*i.e.* down to zero emissions). A tax on emissions would be one such example. Such policy has the advantage that it can provide incentives for innovation above and beyond that which seems feasible – *i.e.* upside surprises may occur. Conversely, a performance standard related to emissions of the same pollutant only provides incentives for innovation to the level of the standard. Innovators have no incentive to develop and market technologies which exceed the standard unless they feel that it will induce a ‘ratcheting’ of the standard by policymakers (see Milliman and Prince 1989 for a general discussion).

52. ‘Depth’, is therefore, distinct from stringency. A measure can be stringent and shallow, or lax and deep; and, depth is by no means correlated with policy instrument type. A tax on carbon content of fuels is ‘deep’, while a tax on vehicle characteristics is ‘shallow’. Similarly, an eco-label can be ‘shallow’ (*i.e.*

indicating whether the product passes some established level of energy efficiency performance) or ‘deep’ (*i.e.* giving the estimated level of performance itself). However, both technology-based standards and performance standards are, by definition, ‘shallow’ in nature. Table 10 gives a possible classification of policy instrument types according to the depth of incentives they provide.

**Table 10. Policy Instrument Types and Depth**

<i>Instrument type</i>	<i>Depth of incentives provided</i>
Taxes, tradable permits	Generally ‘deep’ incentives, but not necessarily so ( <i>i.e.</i> product taxes based on discrete characteristics)
Information-based measures (e.g. ‘continuous’ labelling)	Potentially ‘deep’ incentives if the label reports actual estimated performance
Subsidies	Potentially ‘deep’ incentives in cases where the allocation of funds targets performance
Performance-based standards, Technology-based standards	By definition, ‘shallow’ incentives

### 3.5. Environmental policy incidence

53. While the sole objective of environmental policy should be to internalise the market externality directly, for reasons of administrative cost, it can be difficult to target the externality directly. Indeed, the vast majority of policies target a proxy for the externality, rather than the externality itself. One of the few policy measures which can be said to have direct incidence on the externality is a CO<sub>2</sub> tax, permit or performance standard. Using this as an example, incidence can be said to be increasingly indirect as one progresses down the following:

- CO<sub>2</sub> emissions
- Fossil fuel use
- Energy efficiency

54. Of course in some cases, the indirect nature of incidence may be intentional – *i.e.* to meet multiple policy objectives. However, if the policy only targets the externality indirectly, this can have important implications for the direction of innovation. The policy measure will provide incentives for technological innovation which ‘saves’ on the proxy for the bad, rather than the bad itself. Alternatively, it will encourage the use of an input which is thought to be less environmentally damaging than some other input which generates the externality.

55. This will certainly result in important environmental benefits. However, since the correlation between the ‘proxy’ and the ‘externality’ is imperfect, the trajectory of innovation will be sub-optimal. More significantly, once the proxy is targeted, the apparent correlation between the proxy and the externality may break down. The relationship between the technological trajectory inducted by the policy which targets a proxy and the optimal technological trajectory with respect to the externality will become increasingly distant (see Johnstone 2007 for a discussion).

## 4. The transfer of environmental technologies

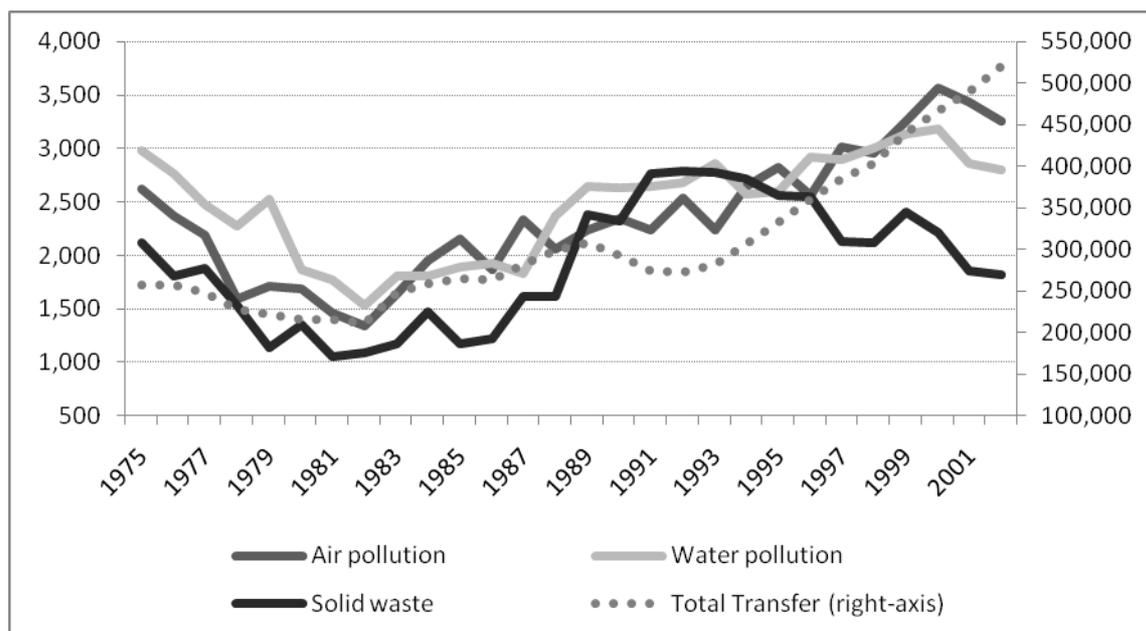
56. International technology transfer (ITT) is an important contributor to economic growth and development. While this is true of OECD economies, it is particularly true of non-OECD economies, since the majority of R&D is still undertaken by OECD countries, and thus non-OECD countries stand to benefit from innovations originating from beyond their borders. However, 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, such as many environmental technologies. For the technology source country, the welfare implications of the transfer of technologies to recipient countries which mitigate transfrontier (e.g. regional pollutants such as sulphur dioxide) or global “public bads” (e.g. greenhouse gas emissions, such as carbon dioxide) are much greater than for other technologies. As such, it is important to develop indicators of technology transfer in the environmental sphere, and to assess the determinants of such transfer.<sup>13</sup>

#### 4.1 Indicators of technology transfer

57. Patent data can also be used to develop indicators of technology transfer (see OECD 2009b and Eaton and Kortum 1999). Indicators of technology transfer<sup>14</sup> are constructed based on counts of *duplicate patent applications* related to selected areas of general ‘environmental’ technology (air pollution, water pollution, solid waste), classified by source country (location of the priority office) and recipient country (location of a duplicate office).<sup>15</sup> A panel of patent counts for a cross-section of all countries and over a time period of 1975-2005 was obtained. Figure 16 gives the totals for the selected areas of ‘environmental’ (air, water, and waste) technologies, together with the level of transfer for all technologies overall (shown on the right-hand axis).

**Figure 16. Transfer of General ‘Environmental’ Technologies by Environmental Medium**  
(Number of duplicate patent applications, worldwide)



58. Figure 17 shows the “direction” of the largest transfers (by volume) of technology in the period 1990-2005, with the relative size of the arrows indicating the magnitude of flows.

<sup>13</sup> Related work is looking at the determinants of transfer of climate change mitigation technologies.

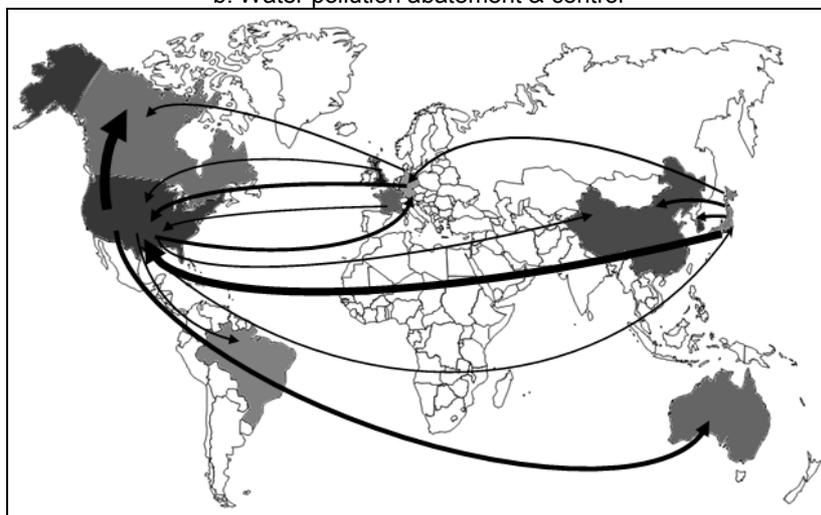
<sup>14</sup> Further work will look at ‘disembodied’ forms of technology transfer, such as international research collaboration and knowledge spillovers.

<sup>15</sup> It is common to present patent data in terms of inventor countries (as in Section 2.1 above) in order to measure national inventive activity. However, in this case the data used to construct the indicators is expressed in terms of ‘priority offices’, since we are concerned with the effect of policy design in different jurisdictions.

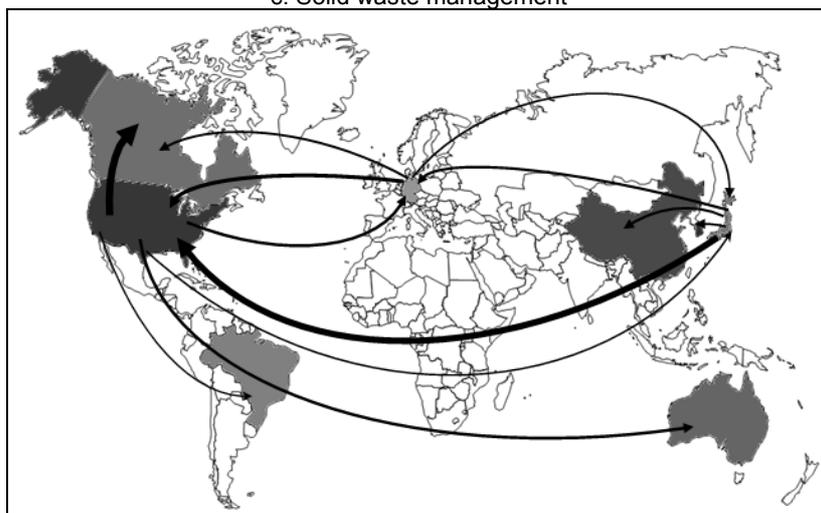
Figure 17. International Transfer of Selected 'Environmental' Technologies (1990-2005)  
a. Air pollution abatement & control



b. Water pollution abatement & control



c. Solid waste management



59. While the degree of economic integration between pairs of countries certainly explains much of the observed pattern, when one looks across the whole spectrum of countries, the effect of the general level of economic integration is less discernible. Assessing the reasons (including the policy factors) for these spatial patterns (as well as for the intensity of the transfers) is the subject of the next section.

60. Although information on levels of technology transfer (in absolute terms) is of interest, it is more useful to study the direction (in relative terms) of transfer between countries. Table 11 provides data on source and recipient countries (bilateral relations) with the largest volume of air, water and waste patents transferred during the period 1990-2005.

**Table 11. Largest Bilateral Transfers in General 'Environmental' Technologies**  
(Number of duplicate patent filings in relevant fields, 1990-2005)

Source country	Recipient country	Air, Water, Waste Transfer	Total Transfer	Share
JP	US	6165	606761	1.02%
US	CA	4189	213142	1.97%
DE	US	3186	161245	1.98%
JP	DE	2770	158348	1.75%
US	DE	2210	136854	1.61%
JP	CN	1978	159479	1.24%
US	AU	1919	114928	1.67%
JP	KR	1671	105494	1.58%
US	JP	1355	129166	1.05%
DE	JP	1299	54973	2.36%
DE	CA	1101	37433	2.94%
US	CN	1072	105180	1.02%
US	BR	1011	50103	2.02%
FR	DE	925	46800	1.98%
FR	US	894	61690	1.45%
US	MX	857	40106	2.14%
JP	CA	847	38444	2.20%
GB	US	801	66259	1.21%
DE	CN	750	43615	1.72%
JP	TW	685	49312	1.39%
GB	DE	587	31292	1.88%
FR	CA	585	25684	2.28%
DE	AU	577	23593	2.45%
DE	BR	576	20481	2.81%
DE	PL	567	11640	4.87%
JP	AU	566	24635	2.30%
GB	CA	564	26414	2.14%
US	GB	480	32176	1.49%

61. While these flows are large in absolute terms, they represent a relatively small share (approx. 1-2%) of total transfers. The share of air, water and waste technologies in total inventive activity

(examined in Section 2.1) is of similar magnitude, indicating that the extent of globalisation for environmental technologies is no greater or less than in other areas of innovation.

62. Conversely, Table 12 provides data on bilateral relations -- where transfers of air, water and waste innovations represent *the highest percentage* of total transfers. The most air-, water-, and waste-intensive transfer relationships involve several Central European countries, as well as countries such as Turkey, Taiwan, South Africa, India, and Mexico.

**Table 12. The Most 'Environmentally' Intensive Bilateral Transfers**  
(Number of duplicate patent filings in relevant fields as a share of total transfer, 1990-2005)

Source country	Recipient country	Air, Water, Waste Transfer	Total Transfer	Share
CZ	PL	23	126	18.25%
JP	PL	94	628	14.97%
CZ	CA	16	115	13.91%
CZ	SK	52	423	12.29%
JP	TR	26	212	12.26%
SK	CZ	15	129	11.63%
CA	PL	14	127	11.02%
LU	CA	20	182	10.99%
CZ	AU	13	124	10.48%
NL	PL	57	564	10.11%
NO	HU	11	118	9.32%
AT	SI	11	118	9.32%
IL	TW	10	109	9.17%
AT	HU	60	657	9.13%
BE	CZ	14	156	8.97%
AT	ZA	37	414	8.94%
DE	IN	33	391	8.44%
JP	CZ	36	434	8.29%
BE	FR	17	205	8.29%
AT	BR	67	808	8.29%
AT	MX	20	242	8.26%
AT	HR	15	183	8.20%
NL	SK	12	147	8.16%
GR	AU	11	137	8.03%
SE	DK	8	100	8.00%
AT	CZ	51	638	7.99%
NL	CZ	21	264	7.95%
AT	SK	40	503	7.95%

Note: Only bilateral relations with total transfers greater than 100 applications over the period covered were included.

#### 4.2 Environmental policy and technology transfer

63. In recent years there has been growing concern that policy heterogeneity across countries may restrict the potential for economies of scale in environmental innovations from being realised. If different countries introduce different types of policy measure, 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.

64. While the effects of policy design on the international diffusion of innovations have 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, and Chakravorty *et al.* 2007).

65. 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 which 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.

66. While the empirical evidence on the effects of environmental policy on trade in goods and services remains limited and ambiguous,<sup>16</sup> 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 policies should be harmonised in order to avoid such effects. It might be imagined that such effects could also be realised through the implementation of identical technology-based standards. This is similar to the arguments put forth by Sykes (1995) and others more generally.<sup>17</sup>

67. Although this may result in an unfragmented market, it may do so at significant cost. If supply conditions (*i.e.* ecological factors) and demand conditions (*i.e.* preferences for environmental quality) differ across countries, these factors should be reflected in domestic policy regimes. There are some arguments for policy harmonisation in certain cases (*e.g.* imperfect enforcement, transfrontier pollution), but it is important that environmental policy not be used as a barrier to trade in order to protect domestic industries (see Ederington and Minier 2003 for a recent empirical study).<sup>18</sup>

68. Conversely, the use of flexible instruments by trading partners may allow for broad markets for innovation, as well as differentiated levels of stringency. In effect, with flexible instruments the level of stringency determines the size of different national markets, without bringing about market fragmentation. This Section examines the proposition that policy flexibility has a positive effect on the international transfer of environmental innovations. Specifically, drawing upon a database of patent applications from a cross-section of OECD and many non-OECD countries evidence is provided for the positive effect of

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<sup>16</sup> See Levinson and Taylor (2008) which provides new results and a methodological discussion of the reasons why positive evidence in this area remains limited.

<sup>17</sup> Standardisation is, of course, important in the presence of network externalities (see Shy 2001). However, this is of limited relevance to environmental concerns.

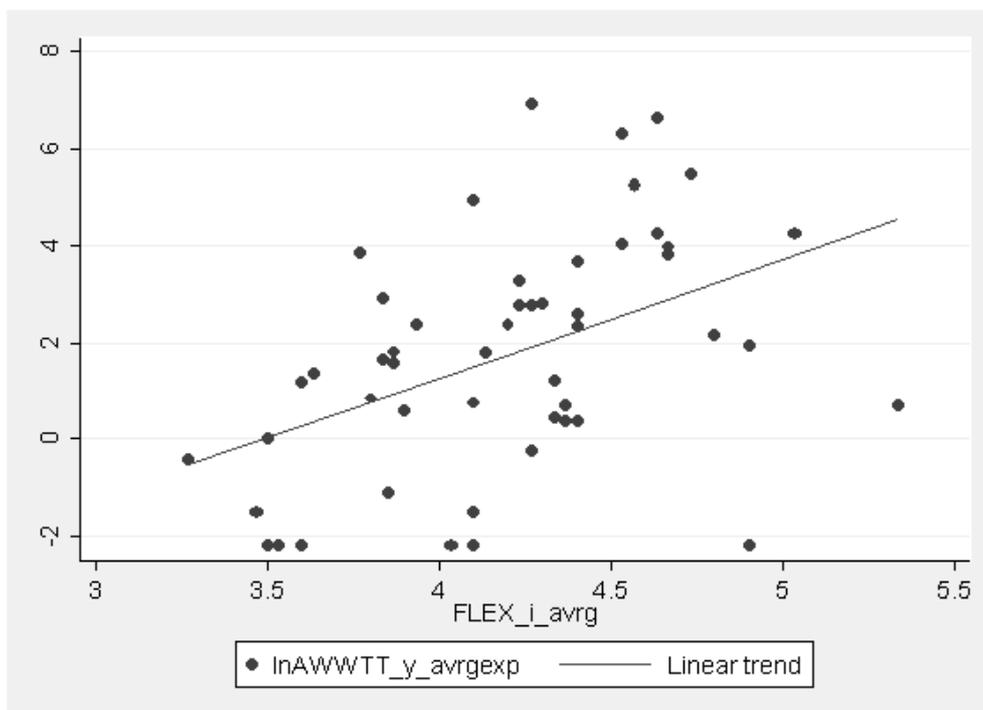
<sup>18</sup> See Greaker and Eggert (2008) for a discussion of the GMO case.

‘policy flexibility’ of the domestic (and foreign) environmental policy regime on the rate of transfer of innovation for environmental technologies – *i.e.* it is argued that a more flexible policy environment leads to greater market worldwide.

69. In particular, it is argued that the more flexible is an individual country’s environmental policy regime, the more likely it is to induce innovations which are able to find markets overseas. The reason for this is intuitive. If more ‘prescriptive’ policies, such as technology-based standards are applied, the technology adoption decision is constrained by the precise characteristics of the standard. Unless other countries adopt standards which are equivalent in nature, the innovations induced are unlikely to be acceptable to permitting authorities overseas. This has the potential to fragment markets for innovation along national (or even sub-national) lines. Conversely, more ‘flexible’ market-based instruments are likely to induce innovations which are potentially applicable in a wider variety of policy settings. This reduces commercial uncertainty associated with research and development, and may allow for the realisation of economies of scale.

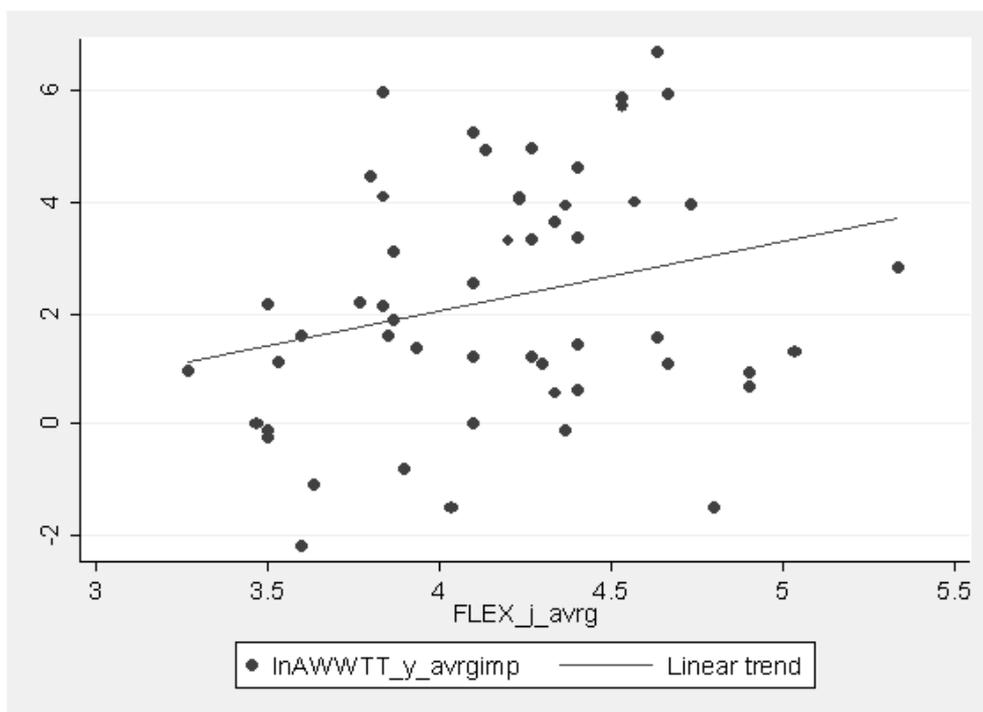
70. Thus, we test a proposition which suggests a relationship between the nature of policy regimes and technology transfer. To do so, we construct a gravity model which allows us to examine all potential bilateral relations between source and recipient countries. The hypothesis is that, other things being equal, more ‘flexible’ environmental policy regimes are likely to generate innovations with broad potential acceptance in overseas markets. Figure 18 shows the index of flexibility of environmental policy regimes (mean responses over the period 2001-03) against ‘exports’ (outflows) of environmental technologies (average levels of duplicate patenting during the same period, in log transformation). The scatter plot in Figure 18 suggests a positive relationship, with the correlation coefficient = 0.45.

**Figure 18. Flexibility of Environmental Policy Regimes and ‘Exports’ of Environmental Technologies**



71. Moreover, countries with more flexible policy regimes are more likely to be able to benefit from inventions developed elsewhere. As such, Figure 19 gives 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.

**Figure 19. Flexibility of Environmental Policy Regimes and ‘Imports’ of Environmental Technologies**



72. Within the environmental sphere, the demand for the technology in question is largely (but not always) determined by the domestic environmental policy framework of the recipient countries. More stringent environmental policies are likely to lead to greater demand for “environmental” technologies in general, and to “imported” technologies in particular. Therefore, for a given level of flexibility, the stringency of environmental policy will determine the size of markets for innovation. As such, it may be necessary to control for differences in the stringency of environmental policy across countries and over time. For this purpose, the WEF index of perceived stringency of a country’s overall environmental regulation is used (described earlier in Section 3).

73. As found in more general studies of technology transfer, the ‘absorptive’ capacity of the recipient country for the new technologies plays a crucial role. Realising the benefits of technology transfer depends upon a capacity to apply (and perhaps even to modify) the imported technologies efficiently. This in turn requires a certain degree of technological sophistication. While the number of scientific personnel or expenditures on R&D in the relevant fields could be used as measures of domestic scientific capacity, in practice, the lack of data for many non-OECD countries (even at the macroeconomic level) prohibits the use of such a measure. We assume that patent data can also be used 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.

74. Technologies may only be transferred if they have been developed in the first place. To capture the stock of inventions in source country that are potentially available for transfer elsewhere, a variable is constructed that reflects the number of patent applications by domestic inventors filed in the current or the

three previous years. This time span is appropriate given the limitations on international patenting imposed by international patent treaties.<sup>19</sup> 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 previous case, 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.

75. Finally, differences in the general propensity to transfer patents between countries and over time are captured through the use of a variable which reflects overall duplicate patent applications filed across the whole spectrum of technological areas. This variable should capture all of the more general economic factors which are likely to influence transfer (*e.g.* common language, geographic distance, commercial relations, strength of intellectual property rights, *etc.*), but which are not specific to ‘environmental’ innovation. The sign is expected to be positive.

76. Based on the discussion above, the following equation is specified:

$$AWWTT_{ijt} = \beta_1 + \beta_2 FLEX_{it} + \beta_3 FLEX_{jt} + \beta_4 STRNG_{it} + \beta_5 STRNG_{jt} \\ + \beta_6 AWWSUPPLY_{it} + \beta_7 AWWABSCAP_{jt} + \beta_8 TOTALTT_{ijt} + \varepsilon_{ijt}$$

where  $i$  represents the source country,  $j$  the recipient country<sup>20</sup>, and  $t = 1998, \dots, 2006$  indexes time<sup>21</sup>.

77. Our dependent variable is a measure of the number of patents in source country  $i$  (the ‘priority’ office) for which protection has also been sought in recipient country  $j$  (the ‘duplicate’ office) in year  $t$ . On the right-hand side of the equation,  $FLEX_{it}$  and  $FLEX_{jt}$  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,  $STRNG_{it}$  and  $STRNG_{jt}$  reflect the degree of stringency of the source and recipient countries’ environmental policy regimes.  $AWWSUPPLY_{it}$  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.  $AWWABSCAP_{jt}$  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. And finally,  $TOTALTT_{ijt}$  is the total number of patents which are transferred from source country to recipient country, and sign is expected to be positive. All the residual variation is captured by the error term ( $\varepsilon_{ijt}$ ). Table 13 gives the basic descriptive statistics for the sample used.

<sup>19</sup> 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 Cooperation Treaty (1970) the applicant may file an international application which allows further 18 months to make any duplicate filings in signatory countries.

<sup>20</sup> There are 101 source and recipient countries in the sample.

<sup>21</sup> That is, 3 years after and 3 years prior to the availability of data on the flexibility index.

**Table 13. Descriptive statistics for the panel dataset**

Variable	Obs	Mean	Std. Dev.	Min	Max
AWWTT <sub>ijt</sub>	21822	0.57	8.27	0	498
FLEX <sub>it</sub>	21822	3.94	0.62	1.7	5.4
FLEX <sub>jt</sub>	21822	3.94	0.62	1.7	5.4
STRNG <sub>it</sub>	21822	4.12	1.31	1.2	6.7
STRNG <sub>jt</sub>	21822	4.12	1.31	1.2	6.7
AWWSUPPLY <sub>it</sub>	21822	421.25	1273.64	0	7790
AWWABSCAP <sub>jt</sub>	21822	109.32	329.02	0	2024
TOTALTT <sub>ijt</sub>	21822	42.74	768.19	0	49584

78. Given the count nature of the dependent variable, the equation is estimated as a negative binomial model using maximum likelihood.<sup>22</sup> Four alternative model specifications are estimated. This includes models where the flexibility index varies over time, placing a constraint on the length of the panel (models 1 & 2). Alternatively, the mean value of the index is used instead allowing for longer panel (models 3 & 4).

79. The empirical results (Table 14) 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.

80. As for differences in policy regimes between the source and recipient countries, the results suggest that countries with more flexible policy measures are both, 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 highly significant in all models estimated.<sup>23</sup> Moreover, controlling for differences in policy stringency (or not) does not affect the qualitative nature of this finding.

<sup>22</sup> For further details on negative binomial models, see Cameron and Trivedi (1998); Hausman, Hall and Griliches (1984).

<sup>23</sup> The only exception is model (2), where the significance level is 10.2%. However, the principal results are confirmed when year fixed effects are included (Table 11).

**Table 14. Policy Flexibility and Transfer**  
(Empirical estimates of the negative binomial regression)

Dependent variable: AWWTT <sub>ijt</sub>	using FLEX <sub>jt</sub>		using FLEX <sub>j_avg</sub>	
	t=2001-03		t=1998-06	t=2001-06
	(1)	(2)	(3)	(4)
Policy Flexibility (FLEX <sub>it</sub> or FLEX <sub>i_avg</sub> )	1.3657*** (0.000)	0.2204 (0.102)	2.1638*** (0.000)	0.5966*** (0.000)
Policy Flexibility (FLEX <sub>jt</sub> or FLEX <sub>j_avg</sub> )	1.0634*** (0.000)	0.6256*** (0.000)	1.4522*** (0.000)	1.1998*** (0.000)
Policy Stringency (STRNG <sub>it</sub> )		0.8262*** (0.000)		0.6698*** (0.000)
Policy Stringency (STRNG <sub>jt</sub> )		0.3354*** (0.000)		0.1202* (0.047)
Supply of Inventions (AWWSUPPLY <sub>it</sub> )	0.0004*** (0.000)	0.0003*** (0.000)	0.0003*** (0.000)	0.0003*** (0.000)
Absorptive Capacity (AWWABSCAP <sub>it</sub> )	0.0012*** (0.000)	0.0012*** (0.000)	0.0011*** (0.000)	0.0011*** (0.000)
Total Technology Transfer (TOTALTT <sub>ijt</sub> )	0.0042*** (0.000)	0.0026*** (0.000)	0.0044*** (0.000)	0.0028*** (0.000)
Intercept	-13.2789*** (0.000)	-12.1151*** (0.000)	-18.6560*** (0.000)	-14.7467*** (0.000)
N	21822	21822	90900	37200
Log pseudolikelihood	-5757.94	-5548.51	-15888.29	-8035.44
(Prob > Chi2)	0.000	0.000	0.000	0.000

P-values in parentheses, based on robust standard errors. \* p<0.05, \*\* p<0.01, \*\*\* p<0.001

81. We note that the findings are robust to the inclusion of year fixed effects (Table 15). Convergence problems prevented us from including year fixed effects for the two models with the full sample, as well as country fixed effects. However, country-specific heterogeneity is already controlled for by a number of regressors in the model that vary across individual country.

**Table 15. Policy Flexibility and Transfer**  
(Empirical estimates of the negative binomial regression, with year fixed effects)

Dependent variable: AWWTT <sub>ijt</sub>	using FLEX <sub>jt</sub>	
	t=2001-03	
	(1)	(2)
Policy Flexibility (FLEX <sub>it</sub> or FLEX <sub>i_avg</sub> )	1.5741*** (0.000)	0.4906*** (0.000)
Policy Flexibility (FLEX <sub>jt</sub> or FLEX <sub>j_avg</sub> )	1.2925*** (0.000)	0.9103*** (0.000)
Policy Stringency (STRNG <sub>it</sub> )		0.7329*** (0.000)
Policy Stringency (STRNG <sub>jt</sub> )		0.2513*** (0.000)
Supply of Inventions (AWWSUPPLY <sub>it</sub> )	0.0004*** (0.000)	0.0003*** (0.000)
Absorptive Capacity (AWWABSCAP <sub>jt</sub> )	0.0012*** (0.000)	0.0012*** (0.000)
Total Technology Transfer (TOTALTT <sub>ijt</sub> )	0.0034*** (0.000)	0.0024*** (0.000)
Intercept	-14.4582*** (0.000)	-13.1599*** (0.000)
N	21822	21822
Log pseudolikelihood (Prob > Chi2)	-5644.45 0.000	-5494.47 0.000

P-values in parentheses, based on robust standard errors.

\* p<0.05, \*\* p<0.01, \*\*\* p<0.001

82. In sum, drawing upon a rich database of patent applications from a cross-section of countries evidence is provided 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. There appears to be a strong relationship between perception of the flexibility of environmental policy regimes in different countries and the spatial scope of diffusion of inventions which are first patented in these countries. These results provide further support for the use of ‘flexible’ instruments (including market-based instruments) in environmental policy. And while the focus of this paper is on the specific case of environmental policy, the discussion is equally applicable to aspects of product and labour market regulation which have implications for technological innovation, such as product and workplace safety.

83. We have argued that ‘differentiated’ and ‘prescriptive’ technology-based regulations can result in fragmented technology markets, with the potential market for the innovations induced fragmented across different policy jurisdictions. International policy coordination would reduce the potential for such fragmentation. For global public goods (such as mitigation of climate change), such coordination 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 are myriad of differentiated and prescriptive policy measures.

84. 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 be welfare-improving. However, this does not mean that the benefits associated with globalised markets for innovation cannot be realised. In effect, it is ‘flexibility’ of policy regimes (rather than relative stringency) which 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 innovations induced.

85. This flexibility is primarily a consequence of the point of incidence of different policy measures. Any policy which focuses on the environmental ‘bad’, rather than mandating a particular 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<sub>2</sub> emission levels, wastewater effluent quality).

## 5. Concluding remarks

86. In this report, data on the extent of innovation and transfer of technologies related to air pollution abatement, wastewater treatment and solid waste management have been presented. These areas represent key components of the development of more general indicators of environmental technology innovation and transfer. On the basis of the evidence presented, the rate of innovation in these areas is no greater than the rate of innovation more generally. In addition, the rate of transfer between countries is no greater than the general rate of transfer.

87. The potential impacts of environmental policy design on innovation have been reviewed. In addition, some empirical evidence has been presented on the determinants of both innovation and transfer. On the one hand, it has been found that policy stringency plays a significant role in inducing innovation. It is, of course, hardly surprising, that an increase in the price of a factor of production (in this case environmental resources) will generate innovation which saves on its use.

88. However, stringency is not the only aspect of the policy regime which encourages innovation. Evidence presented indicates that a more ‘flexible’ policy regime will induce more innovation than a regime which is ‘prescriptive’ in nature. By allowing potential innovators to identify the most efficient means of achieving a given environmental objective, policy flexibility provides incentives for innovation above and beyond those provided by policy stringency. Of course, administrative and monitoring costs may prevent the use of ‘flexible’ instruments in some cases.

89. Environmental policy flexibility also provides incentives for the wide international diffusion of incentives induced. This highlights the importance of domestic policy design in the realisation of international market opportunities. The effects arise both on the demand side by allowing potential adopters of technology to draw upon the global market, and on the supply side, by encouraging innovators in source countries to develop technologies with wide market appeal.

90. In addition, results presented indicate that a ‘stable’ policy regime is likely to induce more innovation than one which is more unpredictable. Uncertain signals give investors strong incentives to postpone investments, including those which lead to innovation. An “unstable” policy regime will add to the risk which investors face in the market, and in doing so serve as a ‘brake’ on innovation. This implies

that governments have an interest to behave in a predictable manner if they wish to induce innovations which achieve environmental objectives at lower cost. Of course with new information (i.e. about environmental damages or abatement costs), it may be efficient to adjust policy conditions. However, there is a trade-off.

91. The results of this work will feed into a forthcoming publication, which will also include chapters on other key environmental areas (climate change mitigation, motor vehicle emissions, sustainable chemistry), as well as refined policy conclusions.

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## APPENDIX

Table A1. Patent Classes for General Environmental Technologies

AIR POLLUTION	IPC Class
Filters or filtering processes specially modified for separating dispersed particles from gases or vapours	B01D46
Separating dispersed particles from gases, air or vapours by liquid as separating agent	B01D47
Separating dispersed particles from gases, air or vapours by other methods	B01D49
Combinations of devices for separating particles from gases or vapours	B01D50
Auxiliary pretreatment of gases or vapours to be cleaned from dispersed particles	B01D51
Chemical or biological purification of waste gases; by catalytic conversion	B01D53/34-36
Chemical or biological purification of waste gases; Removing components of defined structure	B01D53/46-72
Separating dispersed particles from gases or vapour, e.g. air, by electrostatic effect	B03C3
Use of additives to fuels or fires for particular purposes for reducing smoke development	C10L10/02
Use of additives to fuels or fires for particular purposes for facilitating soot removal	C10L10/06
Blast furnaces; Dust arresters	C21B7/22
Manufacture of carbon steel, e.g. plain mild steel, medium carbon steel, or cast-steel; Removal of waste gases or dust	C21C5/38
Exhaust or silencing apparatus having means for purifying, rendering innocuous, or otherwise treating exhaust	F01N3
Exhaust or silencing apparatus combined or associated with devices profiting by exhaust energy	F01N5
Exhaust or silencing apparatus, or parts thereof	F01N7
Electrical control of exhaust gas treating apparatus	F01N9
Monitoring or diagnostic devices for exhaust-gas treatment apparatus	F01N11
Combustion apparatus characterised by means for returning flue gases to the combustion chamber or to the combustion zone	F23B80
Combustion apparatus characterised by arrangements for returning combustion products or flue gases to the combustion chamber	F23C9
Arrangements of devices for treating smoke or fumes of purifiers, e.g. for removing noxious material	F23J15
Shaft or like vertical or substantially vertical furnaces; Arrangements of dust collectors	F27B1/18
Alarms responsive to a single specified undesired or abnormal condition and not otherwise provided for, e.g. pollution alarms; toxics	G08B21/12-14
Incinerators or other apparatus specially adapted for consuming specific waste or low grade fuels; of waste gases or noxious gases	F23G7/06

<b>WATER POLLUTION</b>	<b>IPC Class</b>
Arrangements of installations for treating waste-water or sewage	B63J4
Treatment of water, waste water, sewage or sludge	C02F
Fertilisers from waste water, sewage sludge, sea slime, ooze or similar masses	C05F7
Chemistry; Materials for treating liquid pollutants, e.g. oil, gasoline, fat	C09K3/32
Devices for cleaning or keeping clear the surface of open water from oil or like floating materials by separating or removing these materials; Barriers therefor	E02B15/04-06
Cleaning or keeping clear the surface of open water; Devices for removing the material from the surface	E02B15/10
Methods or installations for obtaining or collecting drinking water or tap water; Rain, surface or groundwater	E03B3
Plumbing installations for waste water	E03C1/12
Sewers - Cesspools	E03F
Fertilisers from waste water, sewage sludge, sea slime, ooze or similar masses	C05F7

<b>SOLID WASTE</b>	<b>IPC Class</b>
Animal feeding-stuffs from distillers' or brewers' waste; waste products of dairy plant; meat, fish, or bones; from kitchen waste	A23K1/06-10
Footwear made of rubber waste	A43B1/12
Heels or top-pieces made of rubber waste	A43B21/14
Medical or veterinary science; Disinfection or sterilising methods specially adapted for refuse	A61L11
Separating solid materials; General arrangement of separating plant specially adapted for refuse	B03B9/06
Disposal of solid waste	B09B
Reclamation of contaminated soil	B09C
Manufacture of articles from scrap or waste metal particles	B22F8
Sawing tools for saw mills, sawing machines, or sawing devices; Edge trimming saw blades or tools combined with means to disintegrate waste	B27B33/20
Recovery of plastics or other constituents of waste material containing plastics	B29B17
Preparing material; Recycling the material	B29B7/66
Presses specially adapted for consolidating scrap metal or for compacting used cars	B30B9/32
Systematic disassembly of vehicles for recovery of salvageable components, e.g. for recycling	B62D67
Transporting; Gathering or removal of domestic or like refuse	B65F
Stripping waste material from cores or formers, e.g. to permit their re-use	B65H73
Hydraulic cements from oil shales, residues or waste other than slag	C04B7/24-30
Calcium sulfate cements starting from phosphogypsum or from waste, e.g. purification products of smoke	C04B11/26
Use of agglomerated or waste materials or refuse as fillers for mortars, concrete or artificial stone; Waste materials or Refuse	C04B18/04-10
Clay-wares; Waste materials or Refuse	C04B33/132
Fertilisers from household or town refuse	C05F9
Recovery or working-up of waste materials	C08J11

Luminescent, e.g. electroluminescent, chemiluminescent, materials; Recovery of luminescent materials	C09K11/01
Production of liquid hydrocarbon mixtures from rubber or rubber waste	C10G1/10
Solid fuels essentially based on materials of non-mineral origin; on sewage, house, or town refuse; on industrial residues or waste materials	C10L5/46-48
Working-up used lubricants to recover useful products	C10M175
Working-up raw materials other than ores, e.g. scrap, to produce non-ferrous metals or compounds thereof	C22B7
Obtaining zinc or zinc oxide; From muffle furnace residues; From metallic residues or scraps	C22B19/28-30
Obtaining tin; From scrap, especially tin scrap	C22B25/06
Mechanical treatment of natural fibrous or filamentary material to obtain fibres or filament; Arrangements for removing, or disposing of, tow or waste	D01B5/08
Textiles; Disintegrating fibre-containing articles to obtain fibres for re-use	D01G11
Textiles; Arrangements for removing, or disposing of, noil or waste	D01G19/22
Paper-making; Fibrous raw materials or their mechanical treatment ; the raw material being waste paper or rags	D21B1/08
Paper-making; Fibrous raw materials or their mechanical treatment; Defibrating by other means of waste paper	D21B1/32
Paper-making; Other processes for obtaining cellulose; Working-up waste paper	D21C5/02
Paper-making; Pulping; Non-fibrous material added to the pulp; Waste products	D21H17/01
Street cleaning; Apparatus equipped with, or having provisions for equipping with, both elements for removal of refuse or the like and elements for removal of snow or ice	E01H6
Street cleaning; Removing undesirable matter, e.g. rubbish, from the land, not otherwise provided for	E01H15
Cremation furnaces; Incineration of waste; Incinerator constructions; Details, accessories or control therefor	F23G5
Cremation furnaces; Incinerators or other apparatus specially adapted for consuming specific waste or low grade fuels	F23G7