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ENVIRONMENTAL POLICY, MANAGEMENT AND R&D

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TABLE OF CONTENTS

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INTRODUCTION

Pollution control and innovation are two areas characterized by market failures. Pollution is a negative externality (since elements of the assimilative capacity of the environment are public goods) while innovation is viewed as a positive externality (since elements of the information generated by innovation are public goods). Therefore, without public policies designed to overcome those market failures, firms pollute too much and do not innovate enough compared with the social optimum. As such, and as noted by Jaffe *et al.* (2005), investments in the development of "green technology" are likely to be below the social optimum because, for such investments, the two markets failures are mutually reinforcing.

Consequently, it is important to assess the factors that drive facilities' decision to engage in R&D investments, and more specifically in environment-related R&D investments. Understanding the role that public policy, and especially environmental regulation, plays with respect to environmental innovation is instrumental in helping policymakers to design "innovation-friendly" environmental regulations. In addition, we also analyse the way in which environmental management within firms affects the decision to engage in environmental R&D.

One should keep in mind that we only look at the determinants of such R&D investments and not at the overall impact of those investments on social welfare. It is not impossible that investments in environmental R&D divert resources away from more socially-beneficial investments. For example, Link (1982) finds that environmental R&D activities may reduce the growth of measured productivity.

Due to the difficulty of measuring innovation directly, empirical studies assessing the impact of environmental policies on innovation generally proxy innovation in one of two ways (see OECD, 2006). The first one is the level of R&D or environmental R&D expenditures and the second one is the number of successful patent applications. Both methods have well-known shortcomings. The first has been criticised on the grounds that R&D is an input to the innovation process rather that an output of it. The second method has been criticised for giving the same importance to every patent even if it is now well-known that no two patents have the same value. Therefore, while one would like to assess technological change by looking at the value of individual patents, such information is not readily available, and we will therefore focus on the decision to engage in general and environmental R&D.

This paper seeks to contribute to the literature on the determinants of the decision to engage in environmental innovation through the analysis of a database held at the OECD Environment Directorate and implemented by research teams in seven OECD countries. (For full details on the project see *www.oecd.org/env/cpe/firms* and Johnstone, 2006.) The data was collected in early 2003 by means of a postal survey of manufacturing facilities with 50 employees or more in the seven OECD countries involved. (Annex 1 provides details on the sampling procedure.) It is found that environmental policy stringency increases the likelihood to invest in environmental R&D, as does the use of more flexible environmental policy instruments. The implementation of environmental management systems and tools also increases the likelihood of investing in environmental R&D, although these two sets of decisions are endogenously determined.

The paper is organised as follow. The next section reviews the literature on the determinants of environmental innovation with a special focus on the effects of different policy instruments. Subsequently, a model of the decision to engage in environmental R&D is presented. Then, in the following two sections we present our data, provide some descriptive statistics and report our results. We conclude in the final section.

BACKGROUND LITERATURE

Since the pioneering work of Schumpeter (1942), technological change is considered to be a three-step process. The first step is invention which corresponds to the creation of new product or process. The second one is innovation which occurs when a new product or process enters the marketplace. The third one is diffusion which describes the process under which firms and/or individuals start to use a successful innovation on a broad scale. As Arrow (1962) pointed out the information generated by all three aspects of technological change can be at least partly a public good. As such, there is a clear need for public policy intervention in order to ensure a socially optimal rate of innovation.

However, by modifying the incentives faced by firms, public policy potentially has an impact not only on the rate of technological change, but on its direction as well. In this paper we are interested in the direction of technological change, specifically with respect to the intensity of the use of the environment. Since the marginal private cost of pollution is usually inferior to the marginal social cost of pollution, firms will tend to generate too much pollution compared with the social optimum. An enlightened regulator should ideally put incentives in place which encourage firms to generate less pollution.

Overall, environmental regulation provides two kinds of incentives: static incentives to pollute less with given technologies and dynamic incentives to develop and adopt cleaner technologies. Some economists (*e.g.* Knesse and

Schultze, 1978; Orr, 1976; Milliman and Prince, 1989) argue that environmental policies' most important benefits (in terms of social welfare) come from the latter effect, rather than from the former effect. According to Milliman and Prince (1989):

> "Indeed the impact of regulation on the pace of technical advance in pollution control had been described as 'over the long haul, perhaps the single most important criterion on which to judge environmental policy' (Knesse and Schultze, 1978) and 'the key to an effective solution of environmental problems' (Orr, 1976)."

However, Parry *et al.* (2003) note that the empirical measurement of the welfare gains from innovation induced by environmental policy has not been given much attention. Using a simple, yet powerful, model, Parry *et al.* (2003) show that, contrary to what is often supposed, the welfare gains from technological innovation are, under a likely range of parameters' values, smaller than the welfare gains from optimal pollution control. However, they show that those welfare gains are "still a sizeable fraction of the Pigouvian welfare gains" (Parry *et al.*, 2003). Therefore, even if the incentives to innovate are not the most important part of the story, if one wishes to assess precisely the net benefits of environmental regulation, one needs to account properly for induced innovation. In the next sections we review the empirical and theoretical literature on the innovation effects of environmental policies.

Theoretical findings

The theoretical literature on the effects of environmental policies on technological change is now quite large. An important feature of environmental policies is that firms facing market-based instruments (MBI) are rewarded (either in terms of non-payment of tax or revenues from the sales or non-purchase of permits) for any emission saved, whereas firms facing command-and-control regulations have no incentives to go beyond the standards. Therefore, not surprisingly, a large share of the literature (*e.g.* Milliman and Prince, 1989; Jung *et al.*, 1996; Downing and White, 1986) provide support for the view that market-based instruments (emissions taxes and tradable permits) offer stronger incentives to innovate than command-and-control (performance-based and technology-based standards) measures. Indeed, it is unlikely that firms will devote significant resources to environmental R&D if the regulator constrains the technologies they can put in place to comply with the regulations, as is the case with technology-based standards.

The literature often provides rankings of various instruments according to the incentives they create for innovation. However, from a public policy point of view, spurring innovation is important only to the extent that the process leads to an increase in social welfare. In an attempt to fill this gap, Fischer *et al.* (2003) compare environmental policy instruments not in terms of the incentives they create to develop cleaner production technologies, but rather on their overall welfare effect. In order to do so, their model incorporates not only the demand side of the innovation market, as is usually the case, but also its supply side. They show that none of the three instruments they consider (taxes, free and auctioned permits) are intrinsically better than the other two at inducing innovation. However, their results suggest that "any of the three policies may induce a significantly greater welfare gain than the other two" under specific circumstances (Fischer *et al.*, 2003). Four important factors explain the different rankings: ability of adopting firms to imitate the innovation, the cost of innovation, the slope and the level of environmental benefit function, and the number of firms generating emissions.

Parry (1998) uses a dynamic model, thus implying that the current state of technology is endogenous, in which non-innovative firms can imitate the new production processes discovered by innovative firms. He concludes that, in such a context, market-based instruments are not significantly superior to command-and-control regulations, unless major innovation occurs. Parry (1998) also points out that if one could adjust the instruments to their optimal level after innovation occurs, the different instruments could lead to very similar levels of efficiency.

Recently, papers started to cast some doubt on the overall supremacy of MBIs to spur innovation. For example, Montero (2002), by introducing imperfect competition in the output market as well as in the permit market, demonstrates that due to strategic behaviour in the decision to engage in R&D, "standards may offer greater incentives than do permits". This is because in an oligopoly a firm's decision to engage in R&D influences the other firms' choice of output, thus creating the potential to hurt the firm's profits.

Empirical findings

A small number of empirical studies on the links between environmental policy and innovation have been undertaken. As noted above, most of these studies measure innovation through data on R&D expenditures and patent grants. Both measures are, of course, imperfect. Firstly, not all innovation involves R&D. This is particularly true in the services sector where managerial innovation is common, but is also true in manufacturing sectors in which innovations can take the form of purchased inputs or technologies. Secondly, patents are by no means the only (or even most common) form of protection of the rents arising from innovation. Indeed, Cohen *et al.* (2000), find that other strategies such as industrial secrecy, marketing strategies and lead times are more prevalent.

Lanjouw and Mody (1996), study the patenting of environmental innovations in Germany, Japan and the United States over the 1970s and the 1980s. In those countries, environmental patenting is responsive to changes in pollution abatement expenditures. An increase in pollution abatement costs will result in an increase in environmental patenting with a one to two-year lag. However, one cannot be entirely confident of their results since other factors influencing innovation (such as industry structure, international competition, *etc.*) are not accounted for in their model.

Jaffe and Palmer (1997) were motivated by the debate around the Porter hypothesis, and the assertion that environmental policy could lead to commercial gains.[1] Due to data limitations they do not try to test the Porter hypothesis directly but rather to provide some information regarding the links between environmental regulation and innovation in general (*i.e.* not innovation directed toward environmentally-friendly processes and products) with existing data. They use data from US manufacturing industries from the late 1970s to the early 1990s. They measure innovation in two ways: total private expenditures on R&D and number of successful patent applications. They focus on the stringency of environmental policy, measured as the pollution control expenditures at the sectoral level, rather than on the choice of instruments. Their results are mixed: an increase in regulatory compliance expenditures leads to an increase in R&D expenditures but does not lead to a statistically significant increase in patenting activity. It is argued that this reflects findings that environmental policies lead to low-value innovations.

More recently, Brunnermeier and Cohen (2003) assess the links between environmental policy pressure and environmental innovation (measured by the number of environment-related patents) in US manufacturing industries during the period 1983 through 1992. They show that, as expected, an increase in pollution abatement expenditures at the industry level results in an increase in environmental patenting. Industries facing international competition are also more likely to be innovative in an environmentally-friendly way. Surprisingly, their results suggest that industries are not responsive to an increase in monitoring and enforcement activities.

Newell *et al.* (1999) examined the effect of energy price changes and regulatory energy efficiency standards on innovation with respect to the energy efficiency of air conditioners and gas water heaters offered for sale in the United States. They find that much of the observed change in energy efficiency can be attributed to overall technological progress. However, energy prices did "induce" innovation, explaining one-quarter to one-half of the increase in energy efficiency in the period 1973-1993. Moreover, the effect of price changes was particularly important when product-labelling requirements were introduced. In addition, energy efficiency standards also have a statistically significant – but more modest – impact on the energy efficiency of appliances offered for sale.

Jaffe and Stavins (1995) look at the role of different policy measures on technology diffusion, although not innovation *per se*. Looking at building insulation practices they find that subsidies for energy conservation have a stronger influence than energy taxes, and that direct regulations (such as building codes) have little effect. However, they emphasise that the greater role of subsidies in encouraging diffusion of insulation practices is not necessarily an argument in favour of their use, not least because the negative scale effects in terms of energy consumption may outweigh the benefits in terms of increased insulation. Moreover, it is difficult to design subsidy schemes which avoid adverse selection.

Popp (2003) examines the effects the tradable permits system for SO_2 emissions as part of the 1990 Clean Air Act had on environmentally-friendly innovation. Comparing patent applications after the introduction of the tradable permit scheme with patent applications submitted under the previous technology-based regulatory system he finds evidence that market-based instruments led to "R&D designed to improve the removal efficiency of scrubbers" (Popp, 2003).

Kerr and Newell (2003) are interested in testing empirically the impact of market-based environmental policies on the diffusion of new technologies. They study the adoption of new technologies induced by the US petroleum's industry phase-down of lead in gasoline. Using a panel of 378 refineries for the period 1971-1995 they show that, as expected, market-based regulations favour the adoption of cost-effective technologies. Similarly, an increase in the stringency of regulations leads to an increase in the adoption of such technologies.

In conclusion, those findings provide some support that environmental policy stringency increases incentives for innovation which is "environment-saving". Also, there is some support that more flexible policy instruments have a greater influence than more prescriptive instruments.

MODEL

A facility compares the expected benefits and costs of investing in R&D (both general R&D and environmental R&D) and proceeds if and only if the expected benefits are greater than the expected costs. In this section we will present some theoretical arguments concerning the role of different factors which are likely to influence a facility's decision to engage in general R&D and environmental R&D.

We model the decision to engage in environmental R&D as two stages. First, the facility must decide whether to invest in general R&D, and then decide whether to devote a share of its R&D budget to environmental matters. This means that we assume that only firms already performing general R&D will devote resources to R&D specifically targeted at environmental matters. One can be confident that this assumption will hold in practice. While many firms in the environmental services sector may be engaged only in environmental R&D, it is very unlikely that a manufacturing facility not performing any general R&D will decide to engage in specifically environmental R&D. This assumption is supported by our data: First, only 15.7% of facilities investing in R&D have a budget specifically for environmental R&D, and; second, among these facilities 93% of those facilities which provided expenditure data report devoting less than 50% of their R&D effort to environmental matters.

In the first stage we are interested in the factors influencing the rate of technological change, while in the second stage we are interested in the factors influencing the direction of technological change. Indeed, the first stage reflects the decision to devote resources to R&D and this affects the potential rate of technological change, while the second stage has more to do with the way funds are allocated to different types of research projects. Specifically, we are interested in determining what affects the direction of technological change toward more environmentally-friendly products and processes.

General R&D

The economic literature on the determinants of R&D is now very large and the public policy framework, firm characteristics as well as market characteristics are thought to influence a firm's decision to undertake such investments. A full discussion of these issues is beyond the scope of this paper, and the reader is invited to examine Jaumotte and Pain (2005a) for an example of recent work in this area, as well as OECD (2006) for a review. However, we will summarise some of the general findings.

Policy conditions

Since innovation creates a positive externality it is not surprising that the decision to engage in R&D is influenced by public policy. First, an intrinsic characteristic of the knowledge produced through R&D is that it is very difficult to exclude others from using it. This makes knowledge a public good and it will be underprovided by the market. As such, the private returns to R&D investments are much lower than the social returns to such investments (for an empirical analysis see, for example, Mansfield *et al.*, 1997). In addition, even in the absence of the public good elements of R&D, there can be particular difficulties in financing R&D optimally. Firstly, R&D is almost always a low-probability but potentially high value investment, which capital markets may have difficulty assessing optimally (Scherer and Harhoff 2000). Secondly, since R&D produces an asset which is specialised, sunk and intangible it can not be used as collateral in capital markets (Jaffe *et al.*, 2003). There is, therefore, a need for policy intervention, whether to increase returns on innovation or to reduce the cost of its generation (see OECD, 2004 for a review of current practice in OECD countries).

In order to address the public good nature of the knowledge produced by R&D legal protection can be provided to help innovators capture potential rents (for example, see Levin *et al.*, 1987). Thus, the strength of a country's intellectual property rights regime is often thought to be a key driver of R&D. However, recent empirical work (*e.g.* Jaumotte and Pain, 2005a and Cohen *et al.*, 2000) generally finds that the intellectual property rights regime is a weak predictor of R&D investment in OECD countries, with many firms favouring other strategies (*i.e.* industrial secrecy, lead times, marketing strategies) to appropriate the rents from innovation. However, for some sectors and for some countries intellectual property rights regimes play a significant role (Cohen *et al.*, 2000).

In addition, many governments have put in place programmes which facilitate co-operation between public research institutions and industry. [See Jaumotte and Pain (2005b) for a discussion.] While many of these programmes are motivated by a wish to realise greater economic benefits from publicly-funded R&D, they may also serve as a spur to private sector R&D. If well-designed, such programmes can encourage the internalisation of knowledge externalities between public and private bodies and, most importantly, between different private bodies.

To address concerns about financing of R&D many governments have put direct financial incentives in place, including tax concessions, grants and loans. In most cases these are designed to ensure that government support does not entirely "crowd out" private investment, but the extent to which this potential concern is addressed varies. More generally, government investment in basic research and higher education can reduce the costs of private R&D, indirectly obviating financial constraints. In the Jaumotte and Pain (2005a) study it was found that while targeted public financial support for R&D has a positive influence on private R&D, the effects are less significant than general policy and framework conditions such as the openness of the economy and regulations on foreign direct investment.

Market characteristics

One of the central hypotheses related to the effect of market structure on innovation was advanced by Schumpeter (1942), who argued that there is a positive correlation between market concentration and innovation. This is expected to be the case because a monopoly is in a better position to prevent imitation and has more financial resources to finance R&D activities. A monopoly may therefore be in a better position to bear the risk and reap the benefits associated with R&D investments. However, in a theoretical paper, Arrow (1962) finds that the efficiency incentives associated with perfect competition are more conducive to innovative activities.

Given the conflicting theoretical results concerning the potential role of market competition on incentives to invest in R&D, it is not surprising to find that the empirical evidence is also mixed. While Gerosky (1990) finds support for the positive effect of competition, Kraft (1987) and Acs and Audretsch (1987) find support for the Schumpeterian hypothesis. (For a review of empirical work in this area see Syrneonidis, 1996.) Therefore, theoretical and empirical support has been found for both a negative and positive relationship between the level of innovation and the degree of market competition.

The spatial scope of the market is also thought to be an important driver of R&D investments: the more global the market in which a firm operates, the more likely the firm is to innovate. As noted by Criscuolo *et al.* (2005), markets serve as a conduit of information, and as such the pool of information available to global firms is greater than that which is available to national and local firms. For similar reasons it is felt that foreign direct investment can be an important conduit, expanding the potential knowledge pool upon which the firm can draw (OECD 2006). Indeed, as noted above, recent empirical evidence (Jaumotte and Pain 2005a) indicates that openness is amongst the most important determinants of investment in R&D.

Firm characteristics

Another important feature of industrial R&D is the frequent necessity for a firm to self-finance such investments due to their risk (Syrneonidis, 1996). Consequently, firms with greater internal financial resources are more likely to invest in R&D. Two explanations have been advanced (see for example Kamien and Schwartz, 1978). First, outside lending may be difficult to obtain because a failed R&D project leaves few valuable tangible assets and given the risk associated with R&D projects, external lenders may be reluctant to finance such projects without substantial collateral. Second, firms may be unwilling to reveal private information that could make the project interesting to outside lenders because they fear that this information will then be available to rivals. Those financing problems are not as strong for firms quoted on the stock market since they have easier access to capital than other firms (Syrneonidis 1996). Moreover, the deepening of venture capital markets in some countries (North America, Netherlands, and United Kingdom), has obviated some of the need to rely upon internal finance (OECD, 2006).

Due in part to such factors, small firms, however, face greater difficulties to finance their R&D projects because, as noted by Jaffe *et al.* (2003), they "have less internally generated cash and/or less access to financial markets". However, firm size may also be important if there are significant economies of scale associated with R&D. The evidence in this area is mixed as well (see Syrneonidis, 1996). However, it would appear that the effect of size is non-linear, becoming less important once a minimum threshold is reached. Empirical evidence indicates that this threshold may be as low as approximately 100 employees (Syrneonidis, 1996).

At the level of the individual facility, managers need to be aware of discoveries within similar sectors. To this end, the way information flows both within and across firms is an important determinant of innovation. One should keep in mind that if information flows too easily it may slow down the rate of discovery since facilities will be reluctant to devote resources to obtain knowledge that they can not appropriate. However, facilities are more likely to share information with other facilities which are part of the same firm than to other firms for obvious reasons. Therefore, being part of a multi-facility firm, by increasing information available to researchers, can potentially be an important driver of R&D, in a manner which is distinct from the effect of firm size.

Environmental R&D

Environmental regulations create a demand for new processes which allow firms to comply with the regulations in a less costly way than currently available processes. This shift in demand affects the pace of technological change. The firm's decision to devote resources to environmental R&D is influenced by three factors: the stringency of the environmental regulatory regime, the type of instrument used, and the manner in which the firm manages environmental issues. In this section we will describe how these factors influence this decision.

Policy stringency

Before the introduction of an environmental policy, firms do not pay for the negative externality they are responsible for and therefore the privately optimal level of pollution is above the socially optimal level. When introducing a new environmental regulation, the regulator explicitly (in the case of a market-based instrument) or implicitly (in the case of a technology-based standard) increases the price of emissions faced by the firms responsible for the pollution. Following from the induced innovation hypothesis, this may have an impact on the type of R&D performed by firms affected by the regulation (Ahmad, 1966).[2]

Therefore, environmental policy is expected to create incentives for a certain type of innovation (*i.e.* environmentally-friendly innovation). The bigger the price change (*i.e.* the more stringent the environmental policy) the more important are the incentives to engage in environmental R&D. The effect on overall R&D (environment and other) is, of course, unknown and may be negative. Nonetheless, the relative stringency of the environmental policy regime is expected to have a positive impact on the likelihood to engage in environmental R&D.

Instrument choice

The allocation of resources to R&D is usually seen to be a function of demand-pull and technology-push factors (Martin, 2002). The two explanations are best thought as being complementary rather than mutually exclusive. In this section we will analyze the main environmental policy instruments in terms of their impact on environmental innovation, keeping in mind both the demand-pull and technology-push views.

In the demand-pull view of the world, first introduced by Schmookler (1966), the potential for innovation is uniformly distributed across the economy. Therefore, more resources for R&D will be allocated to potentially larger markets because the expected benefits of innovation are greater. However, the size of the market depends upon the choice of environmental policy instrument. The greater the flexibility of the policy instrument, the bigger the demand for environmentally-friendly products and processes.

First, technology-based standards provide weaker incentives to innovate than flexible instruments (market-based instruments and performance-based standards). Indeed, under a flexible instrument if a firm decides to engage in environmental R&D to come up with a new process which complies with the regulation, there is potentially a market for whatever process the firm identifies. This is not the case for more prescriptive technology-based standards. We argue that very few firms will be willing to engage in environmental R&D in this situation.

The risk associated with investment in R&D is likely to be greater under a technology-based standard than with more flexible instruments. If there is no change in the policy the technological "space" for potential innovation is constrained by the wording of the standard itself. Broadening this space is then dependent upon inducing a change in the standard (*e.g.* via lobbying the regulatory authorities), which implies a significant political risk. However, if the regulatory authority adjusts the standard to reflect the characteristics of the innovation, the potential returns are much greater. In effect the innovator will have a guaranteed market. As such, the distribution of returns is likely to be more skewed under technology-based standards than under more flexible instruments. Devoting resources to R&D under such a standard can be seen as a gamble which firms are unlikely to take.

Second, among flexible instruments, market-based instruments provide stronger incentives to innovate than performance-based standards. Indeed, once a firm reaches the prescribed standard, it faces no incentives to reduce its emissions further. The very fact that MBIs provide incentives to go toward zero emissions (since each firm has to pay for every unit of emissions) increases the space of relevant innovations and therefore the market size. Therefore, MBIs are expected to have a greater impact on the likelihood to engage in environmental R&D than performance-based standards, which in turn are expected to have a greater impact on the likelihood to engage in environmental R&D than technology-based standards.

In the technology-push view of the world, innovation is determined in large part by exogenous scientific advances. However, the potential for innovation is unevenly distributed across sectors depending upon factors such as their maturity, capital turnover and other factors. Thus, the potential for innovation is located in sectors with significant technological opportunities. Therefore, it is less expensive to innovate and the R&D effort will be concentrated in those sectors. Moreover, opportunities within a sector may vary through time. For instance, there may be exogenous advances in technological areas which have significant environmental implications, encouraging firms to redirect their investment funds away from other types of R&D.

However, public authorities can influence technological opportunities. For instance, environmental authorities frequently introduce technological assistance programmes in specific areas. By doing so, regulators provide information on environment-related technological capabilities, and therefore "distort" the potential for innovation toward environmentally-friendly processes and products. Indeed, such programmes lower the cost of innovation in those sectors because firms do not have to devote resources to gathering the information provided by the regulator. Therefore, technological assistance programmes in the area of environmental technology are expected to have a positive impact on the likelihood to engage in environmental R&D.

Environmental management within facilities

Corporate governance and management systems internal to the firm may also affect the innovativeness of firms and facilities (see Crespi, 2004; Munari and Sobrero, 2003 and Tylecote and Conesa, 1999). The arguments put forward revolve around the principal-agent relationship which exists between shareholders and managers, and the skewed relationship between risk and returns for R&D investments. It is argued that since shareholders are better able to diversify their risk they may be more willing to allocate resources to R&D than managers whose utility functions are more closely tied to the individual investment, and thus are likely to favour lower-risk investments. Relative influence of the two groups and how this relationship is managed is therefore thought to be key to the allocation of resources to R&D.

In addition, it is hypothesised that the composition of the board of directors has an influence on the decision to invest in R&D. In particular, it is felt that the more "insiders" (managers) there are on the board the greater the likelihood that resources will be allocated to R&D since "decision-makers should have appropriate information about the firm's operations in order to enhance innovation" (Lacetera, 2000). And finally, the general system of managerial control applied is thought to be an important determinant, with a distinction drawn between strategic control in which the planning horizon is more long-term, and financial control which is thought to be more short-term. It is argued that firms in which control is more strategic tend to have better mechanism for consistent information flows between shareholders and management (Munari and Sobrero, 2003).

There is mixed empirical support for these hypotheses (see Crespi, 2004 for a review of the evidence). With respect to the questions addressed in this paper, the key concern is whether the arguments put forward have implications for the "direction" of innovation. More specifically, do environmental management systems and practices have implications for the share of R&D allocated toward environment-related concerns? Following from the general arguments forwarded above concerning R&D in general, the generation of relevant information and the exercise of control are likely to be key factors in determining the share of resources devoted toward environmental R&D.

The introduction of different environmental management practices might, therefore, be hypothesised to have a significant influence on the decision to invest in environmental R&D. The presence of an environmental management system (EMS) or different environmental management tools such as environmental accounting and environmental training programmes may generate information which facilitates efficient investments in environmental R&D.

In addition, the designation of an individual with explicit responsibility for environmental matters within the firm or facility may increase the likelihood of such investments being undertaken. The presence of such an individual may improve information flows concerning environmental matters, and may allow for greater control. However, whether or not such control can be exercised is likely to depend upon the institutional location of the individual responsible. Somebody in a position to influence the allocation of financial resources within the firm or facility is more likely to obtain support for investments in environmental R&D.

DATA AND DESCRIPTIVE STATISTICS

Most previous empirical studies of the determinants of environmental innovation are conducted at the sector-level in the United States (*e.g.* Jaffe and Palmer, 1997 and Brunnermeier and Cohen, 2003) and therefore the authors are not able to control for facility or firm-specific characteristics which are likely to affect the decision to engage in environmental R&D. The few studies conducted at the firm-level focus on large companies doing some R&D (*e.g.* Scott, 1997 and Scott, 2003) so one can only estimate why facilities devote more resources to R&D, but not the determinants of the decision to devote any resources at all. In addition, apart from Popp (2001), empirical studies do not test for the effects of differences in environmental policy instruments on innovative activities.

Our dataset differs from the ones used in previous studies in many ways.[3] First, the data was collected by means of a postal survey undertaken in seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway and the United States) at the facility level (see *www.oecd.org/env/cpe/firms* for a discussion of sample procedure). Annex 1 provides information on the survey protocol. The data covers facilities in all manufacturing sectors and not only those in the more polluting sectors. The diversity in countries and sectors sampled implies a greater variation across policy frameworks, technological opportunities, and other factors which will allow for the generation of more reliable estimates of different potential determinants of environmental innovation.

Respondents were CEOs and environmental managers. Response rates range from approximately 9% to 35%, with a weighted mean of almost 25% (see Table 1). For a postal survey this is satisfactory, particularly since previous industrial surveys undertaken in the environmental sphere in many of the countries included in the survey have tended to have very low response rates. For instance, in a review of 183 studies based on business surveys published in academic journals Paxson (cited in Dillman, 2000) reports an average response rate of 21%.

Table 1. **Response rate by country**

	Response rate
Canada	25.0%
France	9.3%
Germany	18.0%
Hungary	30.5%
Japan	31.5%
Norway	34.7%
United States	12.1%
Total	24.7%

While surveys undertaken as part of official data collection exercises may have higher response rates, in many such cases there are legal obligations to respond. Other studies also focus on large firms (*e.g.* Standard and Poor 500) or firms with other attributes (*i.e.* listed on the stock exchange) which are likely to have higher response rates. Indeed, given the population sampled, the response rate was higher than had been anticipated.

Table 2 provides data on the number of respondent facilities by industrial sector for the seven countries. While the sectoral data is available at the ISIC two-digit level (24 sectors), the data is presented in somewhat aggregated form below. Annex 2 provides a comparison of the population of facilities at the two-digit level with our sample for five countries. In the case of Norway, on the basis of chi-square test the sample is not significantly different from the population of facilities in terms of size classes (50-99 employees; 100-249 employees; 250-499 employees; and, > 500 employees). In the case of Germany the distribution of the sample is statistically different from that of the population by sector. Facility size data is not available. In the case of Japan, the sectoral distribution of the sample is representative, but not the size distribution. For France and Hungary, only firm-level data is available when using a cut-off of 50 employees. However, Annex 2 provides relevant graphs for visual inspection.

Table 2. **Survey respondents by sector and by country**

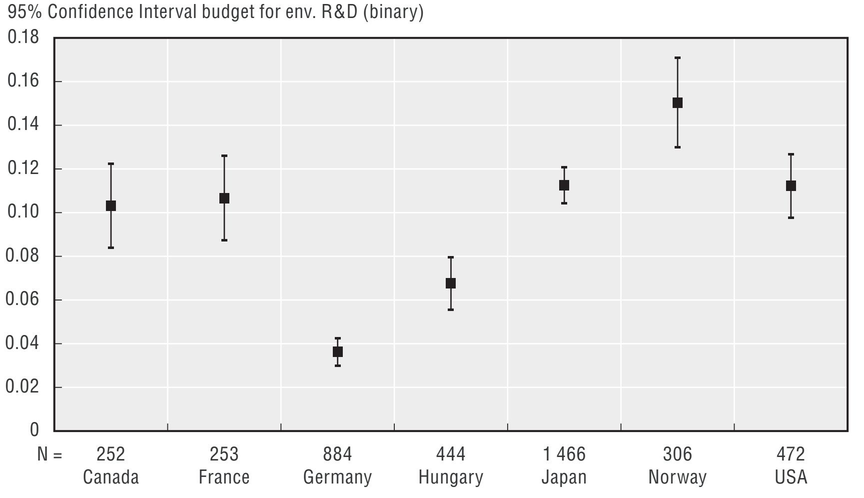
	ISIC Classification	Canada	France	Germany	Hungary	Japan	Norway	United States	Total
Food beverage and tobacco	Sectors 15-16	23	44	77	68	138	33	37	420
Textiles, apparel, leather	Sectors 17-19	8	13	40	50	72	10	12	205
Wood products and furniture	Sectors 20 and 36	32	12	26	27	32	49	34	212
Paper, publishing and printing	Sectors 21-22	22	17	92	21	129	25	24	330
Fuel, chemicals, rubber, plastics	Sectors 23-25	40	48	149	54	195	24	126	636
Non-metallic mineral products	Sector 26	13	13	34	21	34	14	20	149
Basic and fabricated metals	Sectors 27-28	42	53	211	52	286	54	129	827
Machinery and instruments	Sectors 29-33	50	47	227	119	439	55	59	996
Motor vehicles and transport equipment	Sectors 34-35	23	19	32	22	113	44	37	290
Recycling and other	Sectors 37-39	3	2	10	29	29	1	5	79
Total		256	268	898	463	1 467	309	483	4 144

Significantly, there are a large number of observations from smaller facilities for which response rates are usually much lower in such surveys. Indeed, in many previous studies small and medium sized enterprises are not sampled at all, a significant shortcoming as regulators increasingly seek to influence the behaviour of smaller sources. In the sample, over 2 500 facilities can be characterised as small or medium sized enterprises (< 250 employees). Given that many of these same facilities are part of multi-facility firms, the true representation of SMEs in the database at the level of the firm is somewhat lower, but still very significant.

Second, we sampled all facilities, and not just those engaged in R&D. Indeed, we have data on facilities engaged in both general R&D and environmental R&D, on facilities engaged only in general R&D and on facilities not doing any R&D at all. So, we can model the decision to engage in general R&D as well as the decision to engage in environmental R&D.

Third, data was also collected on the environmental policy regime in which facilities operate. Since most environmental policies target facilities and not firms, it is very important to have access to facility-level data in order to estimate the real impact of those policies. Indeed, if one uses firm-level or industry-level data, it is hard to know precisely which types of environmental policies are imposed, and thus it is almost impossible to compare the effects of different instruments.

Figure 1. **Proportion of facilities with environment-related R&D by country**

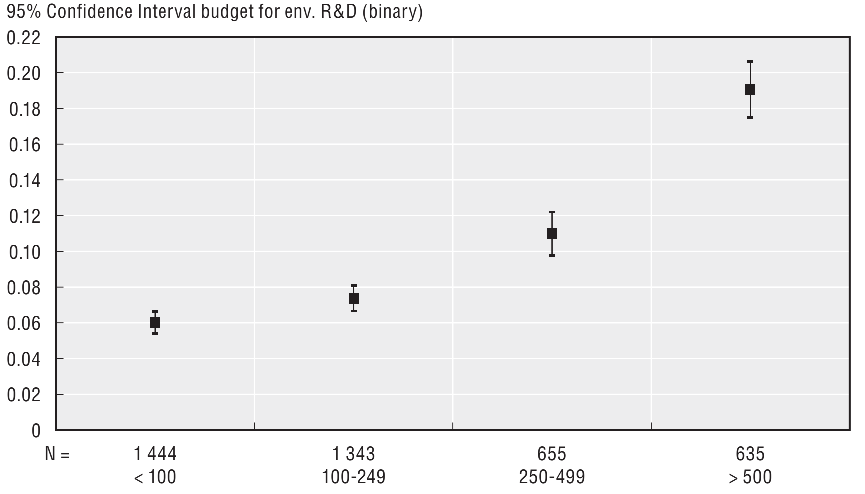


In our sample, 58.7% of facilities report that they have R&D expenditures, and 9.3% of facilities report having invested in environment-related R&D. Figure 1 shows the proportion of facilities reporting that they have environment-related R&D expenditures by country. Norway has the highest percentage with just under 15% reporting having done so, while in the case of Germany it is only 3.6%. For four of the seven countries (France, Canada, Japan and the United States), the proportion is approximately 10%.

Figure 2 shows the proportion of facilities with environment-related R&D budgets according to facility size. As can be seen clearly, larger facilities (more than 500 employees) are more likely to have undertaken such investments, with almost 20% reporting having done so, while the figure is less than 10% for facilities with less than 250 employees. In the sample as a whole, the average size of facility responding affirmatively had over 720 employees, while for those who had responded negatively the figure was less than 300.

The data appears to be consistent with data obtained from other surveys. For instance, according to statistics on research and development from the US National Science Foundation (available online at: *www.nsf.gov/statistics/nsf*05305/*htmstart.htm* accessed 8/31/2005), 55.3% of US companies with more than five employees in the manufacturing sector report R&D expenditures for 2001. In our sample 51.2% of US manufacturing facilities (with more than 50 employees) are engaged in R&D. Among those, 15.7% report having a R&D budget specifically for environmental matters.

Figure 2. **Proportion of facilities with environment-related R&D by facility size**



For the case of Japan, the reliability of the R&D data can also be examined by comparing the OECD survey with data collected as part of the *Survey of Research and Development* 2002, which has been conducted in Japan for more than a decade. In the survey firms are requested to provide information on R&D expenditures from the past year from 31 March 2002 or some other settling day in the region of this date. The survey was targeted at companies and special corporations with capital greater than 10 million yen. Approximately 13 000 firms are subjects of the survey and approximately 83% replied. As in our study, respondents were requested to provide information on the specific purposes of the research expenditures, including environmental conservation. Among 4312 facilities which replied to this question, 8.4% or 360 facilities had environment-related research expenditure. In the OECD survey the corresponding figure was 12%.

Given the information obtained through our questionnaire we are able to construct two binary variables reflecting the decisions to invest in general R&D (GENRD) and in environmental R&D (ENVRD). Ideally, one would want to use the value of environmental R&D expenditures, but there are many missing observations for this variable in the database. Moreover, it is potentially subject to serious measurement error.

General economic variables

The survey also collected information on the market in which the facility operates, on the facility's financial constraints as well as on the facility size. These variables are used in the estimation of general environmental R&D, and we will now describe those variables. (Descriptive statistics on these and the other variables discussed are presented in Tables 3 and 4.)

As discussed before, market characteristics are important in explaining a facility's propensity to innovate. The respondents were asked to report the number of competitors on the market for its most commercially important product during the past three years. We created class variables. COMP5 if a facility has less than five such competitors, COMP5-10 if a facility has between five and ten competitors and COMP10 if it has more than ten competitors. The expected effect of those variables on the decision to engage in general R&D is uncertain.

Table 3. **Descriptive statistics – General R&D**

	Mean	Standard deviation	Number of cases
GENRDDEP	0.565	0.496	4 092
LOSS	0.218	0.413	4 092
PROFIT	0.572	0.495	4 092
LOCAL	0.085	0.279	4 047
REGIONAL	0.108	0.311	4 047
GLOBAL	0.389	0.488	4 047
COMP5	0.271	0.445	4 015
COMP10	0.375	0.484	4 015
EMP50	0.407	0.491	4 092
EMP500	0.156	0.363	4 092
NUMFAC	0.487	0.500	3 865
CANADA	0.062	0.240	4 092
FRANCE	0.062	0.242	4 092
GERMANY	0.218	0.413	4 092
HUNGARY	0.109	0.311	4 092
JAPAN	0.359	0.480	4 092
NORWAY	0.075	0.263	4 092
SECTOR2	0.049	0.215	4 092
SECTOR3	0.051	0.220	4 092
SECTOR4	0.079	0.269	4 092
SECTOR5	0.152	0.359	4 092
SECTOR6	0.036	0.186	4 092
SECTOR7	0.198	0.399	4 092
SECTOR8	0.241	0.428	4 092
SECTOR9	0.069	0.253	4 092
SECTOR10	0.006	0.076	4 092

Table 4. **Descriptive statistics – Environmental R&D**

	Mean	Standard deviation	Number of cases
ENVRDDEP	0.164	0.370	2 313
STRING1	0.359	0.480	2 313
STRING3	0.173	0.378	2 313
INPTBANB	0.514	0.500	2 313
TECHSTDB	0.590	0.492	2 313
PERFSTDB	0.716	0.451	2 313
POLTAXB	0.613	0.487	2 313
INPTAXB	0.668	0.471	2 313
TECHASSB	0.444	0.497	2 313
EMS	0.083	0.276	2 224
EMPACCT	0.332	0.471	2 226
EMPTRAIN	0.547	0.498	2 245
ENVDEPT	0.163	0.370	2 305
FINANCE	0.040	0.196	2 305
SENIOR	0.246	0.431	2 305
PROD	0.116	0.320	2 305
LOCOTHER	0.137	0.344	2 305
CANADA	0.072	0.258	2 313
FRANCE	0.046	0.210	2 313
GERMANY	0.264	0.441	2 313
HUNGARY	0.083	0.275	2 313
JAPAN	0.346	0.476	2 313
NORWAY	0.091	0.288	2 313
SECTOR2	0.045	0.207	2 313
SECTOR3	0.053	0.224	2 313
SECTOR4	0.062	0.242	2 313
SECTOR5	0.158	0.365	2 313
SECTOR6	0.039	0.193	2 313
SECTOR7	0.201	0.401	2 313
SECTOR8	0.265	0.441	2 313
SECTOR9	0.067	0.250	2 313
SECTOR10	0.006	0.078	2 313

Facilities were also asked to characterise their market's scope: local, national, regional and global. Based upon those responses, we created the variables LOCAL, NATIONAL, REGIONAL and GLOBAL. Taking NATIONAL as the reference, the coefficient of LOCAL is expected to be negative while the coefficient for REGIONAL[4]and GLOBAL are expected to be positive.

Facilities were also asked to assess their financial performance over the last three years: large losses, small losses, approximately zero profits, small profits and large profits. Using the replies to this question we construct three class variables: LOSS, NOPROFIT and PROFITS. Following our discussion in the previous section, taking NOPROFIT as the reference, LOSS is expected to have a negative impact on the decision to engage in general R&D, while PROFIT is expected to have a positive impact on this decision.

As discussed before, a facility's size is also an important determinant of its innovative activities. We use the average number of full-time employees over the last three years. In order to allow for non-linear effects, we decided to create classes: less than 100 (EMP50), 100-499 (EMP100) and more than 500 (EMP500). Taking EMP100 as the reference, EMP50 is expected to have a negative impact on the decision to engage in R&D while EMP500 is expected to have a positive impact on this decision.

And finally, as discussed before, being part of multi-facility firm increases an individual facility's access to information which is relevant for R&D. We are able to construct a dummy variable NUMFAC reflecting whether a facility belongs to a multi-facility firm. NUMFAC is expected to have a positive impact on the decision to engage in general R&D.

One should also note that we do not have access to panel data. This implies we are effectively assuming that the R&D decision is contemporaneous with the different incentives reflected in the different explanatory variables. However, most of our data is not really a single-year snapshot, but more of "state" or "perceived state" in the recent period. Stated differently we mostly use stock variables rather than flow variables.

Environmental policy variables

In the questionnaire, facilities were asked to describe the stringency of the environmental policy regime to which they are subject. The three options were: "not particularly stringent", "moderately stringent" and "very stringent". One should keep in mind that this is a perception variable which is likely to be related to the perceived cost of compliance, rather than explicitly to the actual stringency level. We create three class variables: STRING1 (not particularly stringent), STRING2 (moderately stringent) and STRING3 (very stringent). Following our discussion in the previous section, taking STRING2 as the reference, STRING1 is expected to have a negative impact on the decision to engage in environmental R&D, while STRING3 is expected to have a positive impact on this decision.

In the questionnaire, facilities were asked to assess different policy instruments in terms of their impacts on their production activities. The four options were: "not applicable", "not important", "moderately important" and "very important". We argue that this introduces some subjectivity in the responses especially between "not applicable" and "not important" and perhaps also between "moderately important" and "very important". Therefore, to address this we construct a binary taking the value 1 if the instrument has a moderately or very important impact on a facility's production activities and 0 otherwise for each of six instruments: input ban (INPTBAN), technology-based standard (TECHSTD), performance-based standard (PERFSTD), input taxes (INPTAX), emissions taxes (POLTAX) and technical assistance (TECHASS). Following our discussion in the previous section, INPTBAN and TECHSTD are expected to have a negative impact on the decision to engage in environmental R&D while PERFSTD, INPTAX, POLTAX and TECHASS are expected to have a positive impact on the decision to engage in environmental R&D.

Environmental management variables

Our questionnaire allows us to construct three variables reflecting the way facilities manage environmental issues. The first variable EMS reflects the presence of an environmental management system in the facility, and takes the value of 1 if this is the case. The second one EMPACCT is a dummy which takes the value 1 if a facility has introduced an environmental accounting system. The third one EMPTRAIN is a dummy which takes the value 1 if a facility has an environmental training programme in place for its employees. Those three variables are expected to have a positive impact on the decision to engage in environmental R&D since they increase a facility's environmental knowledge base.

In the questionnaire, facilities were also asked to describe the institutional location of the person (if any) with explicit responsibility for environmental concerns. The options were: "Senior Management" (SENIOR), "Production/Operations" (PROD), "Finance/Accounting" (FINANCE), "Specialised Environmental Department" (ENVDPT) and "Other" (LOCOTHER). Following our discussion in the previous section, having designated somebody as having such responsibility is expected to have a positive impact on the decision to engage in environmental R&D. In addition, we expect the marginal effects for SENIOR and FINANCE to be greater than the coefficients for ENVDPT, PROD and LOCOTHER since the two former are more likely to be in a position to affect the allocation of financial resources for R&D purposes.

EMPIRICAL ANALYSIS

As described in the third section, we model the decision to engage in environmental R&D in two stages. First, facilities decide whether or not to engage in R&D. Then, among the facilities performing general R&D, we examine why some decide to devote R&D resources specifically to environmental matters. In this section we report the result of our probit estimations.

Decision to engage in R&D

First, we run a probit regression for the decision to engage in general R&D (GENRDDEP). We do not have data on the public innovation policy framework which, as discussed earlier, is an important driver of innovation activity. Those factors are likely to be sector and country-specific and we can therefore control for them by including sector and country dummies. Results are given in Table 5. The sample size is 3 778 and the log-likelihood function is –2 442.10.

As expected, the scope of the market as well as the facility's business performance have a positive and significant impact on the decision to engage in general R&D. Facilities which report positive profitability (PROFIT) over the last three years are more likely to engage in R&D than those who report that "revenue

Table 5. **Probit model of the determinants of general R&D**

	Coefficient	Standard error	P-value
Constant	–0.133	0.112	0.234
LOSS	–0.144	0.064	0.025
PROFIT	0.118	0.056	0.034
LOCAL	–0.320	0.080	0.000
REGIONAL	0.096	0.079	0.224
GLOBAL	0.105	0.054	0.052
COMP5	–0.151	0.054	0.005
COMP10	–0.031	0.050	0.534
EMP50	–0.056	0.048	0.244
EMP500	0.033	0.064	0.604
NUMFAC	–0.065	0.045	0.148
CANADA	0.412	0.104	0.000
FRANCE	–0.152	0.108	0.157
GERMANY	0.547	0.081	0.000
HUNGARY	–0.161	0.092	0.079
JAPAN	0.265	0.077	0.001
NORWAY	0.625	0.104	0.000
SECTOR2	0.040	0.114	0.725
SECTOR3	0.158	0.115	0.170
SECTOR4	–0.209	0.096	0.030
SECTOR5	0.179	0.083	0.032
SECTOR6	0.287	0.127	0.023
SECTOR7	0.134	0.079	0.088
SECTOR8	0.240	0.078	0.002
SECTOR9	0.070	0.103	0.496
SECTOR10	0.098	0.280	0.726

approximately covers costs" (the reference), while those reporting a loss (LOSS) are less likely to report that they have invested in general R&D. Both variables are significant at the 5% level. Thus, financial performance matters a great deal in explaining a facility's innovative behaviour, and this is in line with the general finding that R&D investments are often self-financed. In addition, the more global the market in which a facility operates, the more likely it is to engage in R&D. Taking those facilities which report that national markets are the most important (NATIONAL) as the reference, LOCAL has a significant negative impact on our variable of interest, while GLOBAL has a positive and significant impact on the decision to engage in R&D at the 10% level. REGIONAL is not statistically significant.

Market concentration has a negative and significant impact (at the 5% level) on the decision to engage in R&D. Facilities with less than five direct competitors in the market for their most important products are less likely to engage in R&D. This result runs counter to the Schumpeterian view. The result may be explained in part because under the Schumpeterian framework firms in less competitive markets can earn supra-normal profits which can be used for R&D investments. However, since we control for a facility's business performance the financial effect of concentration is not captured by this variable, while the advantages of competition, as forwarded by Arrow (1962) remain.

We decided to take medium-sized facilities (with 100-499 employees) as the reference for facility size. As expected, smaller facilities (with 50-99 employees) are less likely to engage in R&D while larger facilities (more than 500 employees) are more likely to do so. However, those two coefficients are not statistically significant. A variable reflecting whether or not the firm of which the facility was a part was listed on the stock exchange was initially included, but it proved to be insignificant and there were concerns about collinearity with size and so the results reported do not include this variable. And finally, we also included the number of facilities (NUMFAC) in our regression, but this variable has no significant impact on the variable of interest.

Overall our results are consistent with the expected effects for most of the determinants and this increases our confidence in our data for the second stage.

Decision to engage in environmental R&D

We now turn our attention to the decision to engage in environmental R&D, focussing on the sub-sample of firms doing some general R&D. The total number of observations available is 2 132. We run a probit regression for the decision to devote some of the R&D resources to environmental matters. Results are given in the first three columns of Table 6.

Interestingly, policy stringency is a very strong driver of the decision to engage in environmental R&D, at least once a certain threshold level of stringency

Table 6. **Models of the determinants of environmental R&D**

	Full model			Reduced form model			Bivariate selection model		
	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Constant	–1.879	0.212	0.000	–1.319	0.182	0.000	–1.319	0.182	0.000
STRING1	–0.264	0.094	0.005	–0.326	0.090	0.000	–0.326	0.090	0.000
STRING3	0.166	0.099	0.093	0.266	0.096	0.006	0.266	0.096	0.006
INPTBANB	–0.128	0.089	0.149	–0.078	0.086	0.363	–0.078	0.086	0.363
TECHSTDB	–0.058	0.101	0.565	0.002	0.095	0.983	0.002	0.095	0.983
PERFSTDB	0.000	0.099	0.999	0.161	0.098	0.101	0.161	0.098	0.101
POLTAXB	0.089	0.103	0.389	0.158	0.100	0.113	0.158	0.100	0.113
INPTAXB	–0.024	0.102	0.814	–0.067	0.102	0.510	–0.067	0.102	0.510
TECHASSB	0.180	0.082	0.027	0.159	0.078	0.042	0.159	0.078	0.042
EMS	–0.027	0.139	0.843	..	..	..	..	..	..
EMPACCT	0.573	0.093	0.000	..	..	..	..	..	..
EMPTRAIN	0.623	0.094	0.000	..	..	..	..	..	..
ENVDEPT	0.377	0.142	0.008	..	..	..	..	..	..
FINANCE	0.332	0.178	0.061	..	..	..	..	..	..
SENIOR	0.127	0.117	0.279	..	..	..	..	..	..
PROD	0.069	0.162	0.672	..	..	..	..	..	..
LOCOTHER	0.189	0.134	0.159	..	..	..	..	..	..
No. of observations	..	..	2 132	..	..	2 313	..	..	2 187
Log-likelihood	..	..	–785.22	..	..	–941.79	..	..	–883.25
Industry dummies	..	..	Included	..	..	Included	..	..	Included
Country dummies	..	..	Included	..	..	Included	..	..	Included

is achieved. Those who report that environmental policy is "not particularly stringent" are much less likely to invest in environment-related R&D than those who report that it is moderately stringent, who in turn are less likely to engage in environmental R&D than those declaring that the environmental policy is "very stringent". This last result is only significant at the 10% level, but provides some support for the induced innovation hypothesis. More stringent environmental regulations, by increasing the cost of polluting, affect the direction of technological change by encouraging search (R&D) for environmentally-friendly innovations.

Technical assistance programmes have a significant impact (at the 5% level) on our variable of interest. By lowering the cost of performing private environmental R&D, such programmes increase the likelihood that a facility will devote some of its R&D resources to environmental matters. Although most of the signs are as anticipated, none of the other environmental policy instruments significantly affect the decision to engage in environmental R&D.

Two of the three variables which reflect a facility's environmental management framework (EMPACCT and EMPTRAIN) have a significant positive impact (even at the 1% level) on the decision to invest in environmental R&D. However, the presence of an environmental management system (EMS) does not. While it might be imagined that this arises from potential multicollinearity between the variables, the correlation coefficients between EMS and the other two management variables is less than 0.1. Thus, it may be that more targeted environmental management tools, rather than general management systems, are more likely to induce innovation. In general, these results are very interesting since they provide strong support for the view that increasing a facility's environmental knowledge base increases the likelihood that a facility will devote resources to environmental R&D.

The results concerning the location of the person with explicit responsibility for environmental matters are quite interesting. First, having an employee explicitly responsible for environmental matters has a positive and significant impact on the decision to engage in environmental R&D only if this employee is located in the finance/accounting department (FINANCE) or in the environment department (ENVDPT). Surprisingly, if this employee is located in senior management (SENIOR) or has responsibility for production operations (PROD) the impact on R&D is not significant. Thus, the key factor on the decision to invest in environment-related R&D appears to be whether the person responsible for environmental resources has influence over the allocation of capital within the facility or is in a position to influence information flows on environmental issues within the facility.

ADDRESSING POSSIBLE BIAS DUE TO ENDOGENEITY

However, the inclusion of the last two sets of variables (environmental management tools and locus of responsibility for environmental matters) raises concerns about possible endogeneity. If the public policy framework affects decisions related to environmental management practices, as well as the decision to invest in environment-related R&D, the results may be biased due to possible endogeneity. In order to address this issue in the first instance, a reduced form equation was estimated, removing the environmental management variables from the model. Results are given in the middle three columns of Table 6.

Most of the results are comparable. However, and interestingly, the results for the policy-related variables change in the expected direction. Firstly, the binary variable reflecting a policy framework which was perceived to be "very stringent" (STRING3) is now highly significant. The magnitude of the coefficient for the variable reflecting a policy framework which is not perceived to be particularly stringent increases in size (and remains negative). In addition, there is now some support for the use of more flexible instruments, with performance standards

(PERFSTD) having a positive and significant influence (at the 10% level). All of the other results remain as before.

In order to further address the potential problem of endogeneity, a bivariate selection model was also run, with the decision to invest in general R&D as the first stage and, if so, whether to invest in environment-related R&D as the second stage. For the second stage the reduced form model is applied, and the results for the latter equation are given in the last three columns in Table 6. The results are comparable to the single equation reduced form model, with one additional finding: the variable reflecting the use of pollution taxes (POLTAX) is now positive and (almost) significant at the 10% level. This result further strengthens the case for the use of more flexible policy measures.

CONCLUSION

This study has assessed the effects of the public policy framework and environmental management practices on the decision to allocate resources to environmental R&D in manufacturing facilities. In the first instance the determinants of general investment in R&D were evaluated. The results for the decision to invest in R&D were consistent with those found in previous studies. For those facilities that had invested in R&D, factors which encourage investment in R&D for environment-related matters was then evaluated, both as single equations and through a bivariate selection model.

With respect to the allocation of R&D resources toward environmental concerns there was strong support for the main hypotheses forwarded. Firstly, perceived environmental policy stringency increases the likelihood that a facility will invest in environment-related R&D. Secondly, it was found that more flexible environmental policy measures such as performance standards (and to a lesser extent pollution taxes) have a positive influence on the decision to allocate resources to environmental R&D. Thirdly, the presence of environmental management systems and practices have a positive and significant effect, although the two decisions are likely to be endogenous. And finally, if the facility has a person explicitly responsible for environmental matters and if this person is located in the finance department or in an environment department, resources are more likely to be devoted to environmental R&D.

It should be emphasised, however, that these results in no way indicate that policy stringency (or even the correct choice of instrument) is welfare-improving. The R&D encouraged may not result in significant innovations of any kind. Moreover, it may also represent a reallocation of resources away from potential uses of capital for R&D in other more productive areas.

Notes

1. For a description of the hypothesis see Porter and Van der Linde (1995). They argue that firms do not undertake all profitable opportunities (*i.e.* some firms are satisficing rather than profit-maximising), and that environmental regulations can act as a signal to firms, encouraging them to undertake investments and to innovate in a manner which would generate both commercial and environmental gains. However, the empirical evidence presented in favour of this finding consists of case studies and as pointed out by Palmer *et al.* (1995), given the very large number of firms facing environmental regulations, being able to point to a few examples in which environmental regulations have generated benefits is far from surprising.
2. To quote Hicks: "a change in the relative prices of the factors of production is itself a spur to invention and to invention of a particular kind directed to economising the use of a factor which has become relatively expensive" (Hicks, 1932). While he was interested in the effect of an increase in real wages on labour-saving innovations, the logic is the same for a regulation which increases the relative price of the environment.
3. For a full description of the survey instrument, the sampling design and the respondents, see Johnstone (2006) and *www.oecd.org/env/cpe/firms*.
4. REGIONAL refers to neighbouring countries, rather than a region within a country.

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Annex 1

Survey Design and Protocol

The survey design and protocol drew inspiration from the principles laid out in Dillman's (1978) "Total Design Method".

Questionnaire design

Designed in collaboration between research teams (approximately 14 researchers) and advisory group members (single representative from each participating country).

Email correspondence and two meetings held at the OECD in 2003 and 2004-18 different versions discussed.

Inputs on survey design obtained from representatives of the OECD's Business and Industry Advisory Committee.

Two-way translation from English into French, Japanese, Norwegian, German and Hungarian.

Pre-tested amongst a selection of representative manufacturing facilities in Japan, Germany and Canada.

Subsequent modifications to ease completion, ensuring that the survey did not exceed 12 pages in length and remained easily legible.

Sampled population of manufacturing facilities with 50 or more employees in seven participating countries.

Sample derived from universal population databases (except for United States – database of TRI facilities).

Stratified sampling by industrial sector (2-digit level) and by facility size (50-99; 100-249; 250-499; > 500).

Data Collection

Postal surveys mailed out to almost 17 000 manufacturing facilities on or around 7 January 2003.

Additional possibility to fill in questionnaire on-line for United States survey (give website address).

Accompanying letter (OECD and Departmental/University letterheads) addressed to Chief Executive Officers and/or "Environmental Managers".

Two postal reminders (in some cases telephone) to a selection of non-respondents within one and two months of initial mail-out to increase response rate.

Annex 2
Representativity of Sectoral Composition of Sample

Figure A1. **Sectoral composition in Norway (by NACE code)**

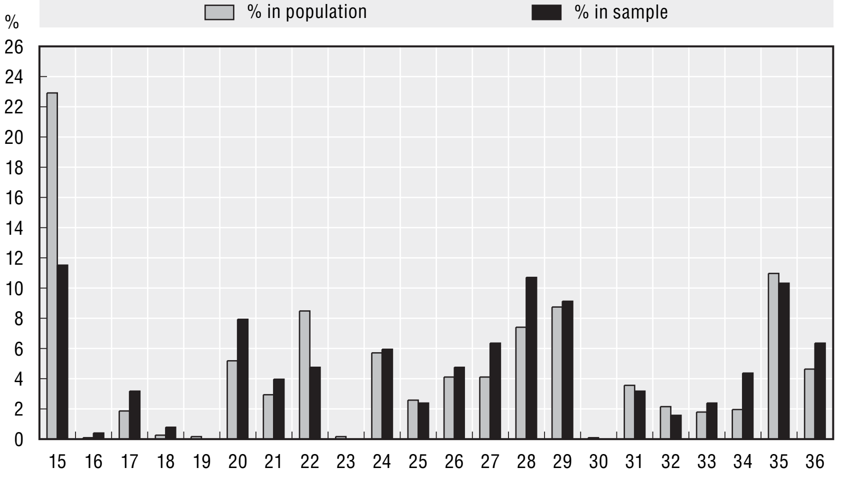

Figure A2. **Sectoral composition in Germany (by NACE code)**

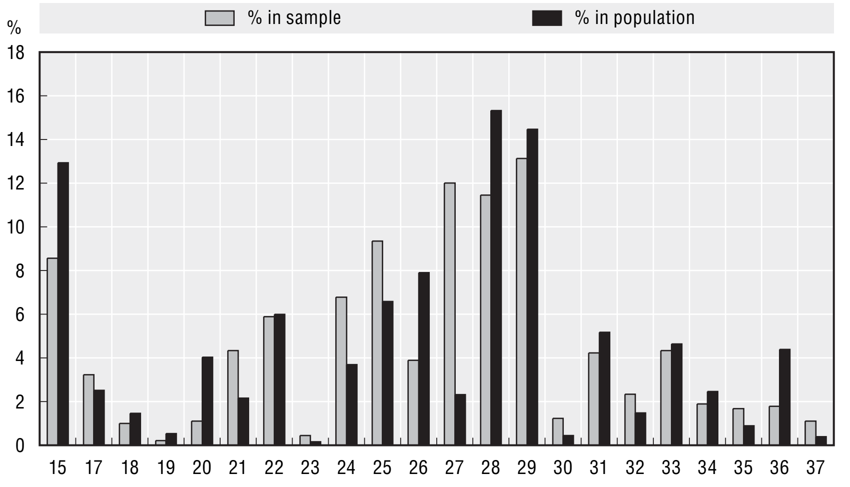

Figure A3. **Sectoral composition in Japan (by JSIC code)**

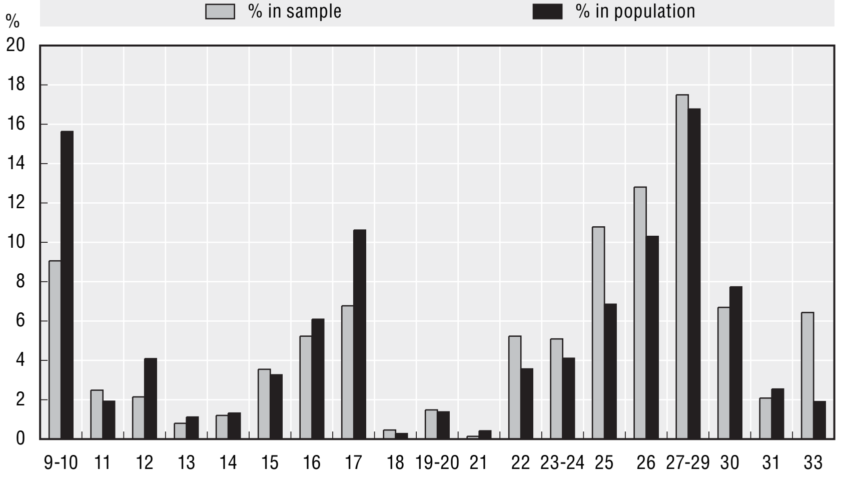

Figure A4. **Sectoral composition in France (by NACE code)**

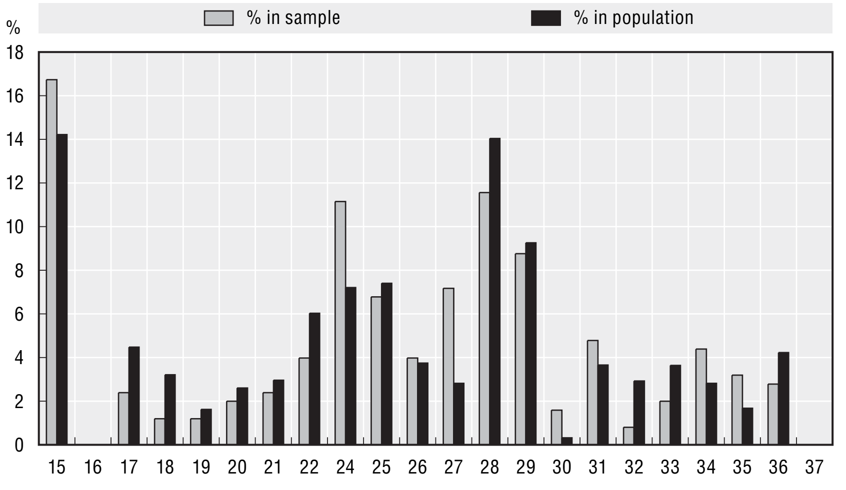

Figure A5. **Sectoral composition in Hungary (by NACE code)**