Environmental Policy, Innovation and Performance : New Insights on the Porter Hypothesis

Paul Lanoie*, Jérémy Laurent-Lucchetti**, Nick Johnstone***, and Stefan Ambec****[1]

This version - December 2009

Abstract

Jaffe and Palmer (1997) present three distinct variants of the so-called Porter Hypothesis. The "weak" version of the hypothesis posits that environmental regulation will stimulate environmental innovations. The "narrow" version of the hypothesis asserts that flexible environmental policy regimes give firms greater incentive to innovate than prescriptive regulations, such as technology-based standards. Finally, the "strong" version posits that properly designed regulation may induce cost-saving innovation that more than compensates for the cost of compliance. In this paper, we test the significance of these different variants of the Porter Hypothesis using data on the four main elements of the hypothesised causality chain (environmental policy, research and development, environmental performance and commercial performance). The analysis draws upon a database which includes observations from approximately 4200 facilities in seven OECD countries. In general, we find strong support for the "weak" version, qualified support for the "narrow" version, but no support for the "strong" version.

Key words: Porter hypothesis, environmental policy, innovation, environmental performance, business performance.

JEL Codes: L21; M14; Q52; Q55; Q58.

* HEC Montreal (paul.lanoie@hec.ca).
** University of Bern and Oeschger center for Climate Change (jeremy.lucchetti@vwi.unibe.ch)
*** OECD (nick.johnstone@oecd.org)
**** Toulouse School of Economics (INRA-LERNA), E-mail: stefan.ambec@toulouse.inra.fr

[1] This research was undertaken when Lanoie was on sabbatical at the INRA (Institut National de Recherche Agronomique) research laboratory of Grenoble. Funding from INRA, FQRSC and the chair on "Sustainable Finance and Responsible Investments" is gratefully acknowledged. We also thank the OECD for providing us with the data. The views expressed herein are those of the authors, and not the OECD or its member countries.

1. Introduction

Porter (Porter, 1991; Porter and van der Linde, 1995) has suggested that pollution is generally associated with a waste of resources, or with lost energy potential: "Pollution is a manifestation of economic waste and involves unnecessary or incomplete utilisation of resources… Reducing pollution is often coincident with improving productivity with which resources are used" (Porter and van der Linde 1995: 98, 105). From this reasoning, Porter argues that 'properly designed environmental regulation can trigger innovation that may partially or more than fully offset the costs of complying with them' (1995, p.98). This has come to be known as the Porter Hypothesis (PH). In other words, it is possible to reduce pollution emissions and production costs at the same time, resulting in "win-win" situations, contrary to the traditional paradigm.

The Porter Hypothesis is controversial. First, the evidence initially provided in its support is based on a small number of company case studies, in which firms were able to reduce both their pollution emissions and their production costs. As such, it can hardly be generalized to the entire population of firms. Second, economists would suggest that, in a perfectly competitive economy, if there are opportunities to reduce costs and inefficiencies, companies should identify them by themselves without the need for government intervention (Oates et al. 1995). Indeed, Ambec and Barla (2005) argue that, analytically speaking, for the Porter Hypothesis to be valid, at least one market imperfection is required in addition to the environmental externality. Examples of such market failures include spillovers in knowledge (Jaffe et al., 2004) or in learning-by-doing (Mohr, 2002). More precisely, when knowledge is public information, a firm does not enjoy the full return of its R&D investment which is shared with its competitors. This leads to underinvestment in R&D. The latter inefficiency can be mitigated with stronger incentives to invest in R&D through stricter environmental regulations. Another market failure that might lead to the Porter Hypothesis is imperfect competition. As shown by Simpson and Bradford (1996) in a model with firms competing à la Cournot on international market, environmental regulations commit a domestic firm to an aggressive cost-reducing program which induces it to behave as a Stackelberg leader vis-a-vis its foreign rival, thereby enjoying a first-mover advantage.[2] Alternatively, market failures may arise out of systemic organisational failures within the firm, such as lack of risk diversification (Kennedy, 1994), contractual incompleteness (Ambec and Barla, 2005), asymmetric information (Ambec and Barla, 2002), and agency control problems (Gabel and Sinclair-Desgagné 2002). In particular, in Ambec and Barla (2002), the manager of a division has private information about pollution abatement costs which is used opportunistically to extract informational rents at the expenses of the company's shareholders. By reducing informational rents, a more stringent environment regulation might increase expected profits and thus be beneficial to shareholders. In all of these cases more stringent environmental regulations might address the two failures simultaneously. Although it is unlikely to address the 'non-environmental' failure in an optimal manner, it could still generate a 'win win' relative to the initial situation.

On the empirical side, Jaffe and Palmer (1997) present three distinct variants of PH. In their framework, the "weak" version of the hypothesis is that environmental regulation will stimulate certain kinds of environmental innovations, although there is no claim that the direction or rate of this increased innovation is socially beneficial. The "narrow" version of the hypothesis asserts that flexible environmental policy instruments, such as pollution charges or tradable permits, give firms greater incentive to innovate than prescriptive regulations, such as technology-based standards. Finally, the "strong" version posits that properly designed regulation may induce innovation that more than compensates for the cost of compliance and improve the financial situation of the firm. While many researchers have tested different versions of the PH empirically, the studies are often partial and the results ambiguous (see next section below).

[2] See also Greaker (2006) for a combination of the two market failures, namely spillovers and market power, in the sector of pollution abatement technologies.

Given this potential for the existence of 'win wins', analysis of the Porter Hypothesis is relevant not only for public policymakers, but also for managers of private firms. First, if the "strong" version of the hypothesis is valid, managers could be much less fearful of stricter government intervention with respect to environmental issues, especially if it comes under the form of flexible policy instruments, and this could affect their lobbying strategies. Second, empirical support of the Hypothesis could lead firms to reconsider their processes in order to identify and correct all possible inefficiencies associated with negative environmental impacts. Third, benefits related to a better environmental performance could go far beyond savings in terms of energy expenditures or cost of materials, as implicitly postulated by the PH. Indeed, more and more analysts show that better environmental performance can increase the probability to be chosen as a supplier, it can lead to a better access to financial markets (and thus a lower cost of capital), it can facilitate risk management, or it can ease recruitment and retention of qualified workers (see, for instance, Hoffman, 2000; Willard, 2005 or Ambec and Lanoie, 2008).

Given the growing importance of environmental issues for businesses and policymakers, given the challenging and controversial nature of the Porter Hypothesis, and given the mitigated nature of the empirical results obtained thus far, assessment of the hypothesis remains an important open research question. In this paper, we use a unique database collected by the OECD in 2003 to test the significance of all the links in the causality chain presented above. This database includes observations from approximately 4200 facilities in seven OECD countries (USA, Canada, Japan, Germany, France, Hungary and Norway). Data was collected on the perceived stringency of the environmental policy regime, the use of different environmental policy instruments (command-and-control regulation, environmentally related taxes, etc.), R&D expenditures allocated specifically to environmental matters, environmental performance with respect to a number of different impacts, business performance, and a number of control variables[3]. To our knowledge, this is the first study to test all the variants of the Porter Hypothesis using data on the four main elements of the causality chain (environmental policies of different types, technological innovation, environmental performance and commercial performance). The proposed exercise allows us to obtain greater insight on the mechanisms at play, and on the empirical validity of the Porter Hypothesis.

The rest of the paper is organized as follows. Section 2 provides a brief literature review on the empirical work related to the Porter Hypothesis[4]. Section 3 presents the empirical model, the econometric strategy and the data. Section 4 outlines the empirical results, while Section 5 provides concluding remarks.

2. Literature survey

We distinguish two broad sets of empirical studies. A first set estimates the impact of environmental regulations on firm's innovation strategy and technological choice, as measured by investment in R&D, in capital and in new technologies, or by successful patent applications. These studies test the first ('weak') version of the PH that more stringent environmental regulations enhance innovation. In the second set of empirical studies, the impact of environmental regulation is estimated on measures of firms' performance, such as productivity and costs. The aim is to test whether more stringent environmental policies can be commercially beneficial to the firm, i.e. the "strong" version. These papers are silent on the process that leads to higher productivity.

In the first set of papers, Jaffe and Palmer (1997) estimate the relationship between pollution abatement costs (a proxy for the stringency of environmental regulation) and total R&D expenditures, as well as the number of successful patent applications in U.S. manufacturing. They found a positive link with

[3] Johnstone at al. (2007a) discuss the background of the project, and present an overview of the data.
[4] A more complete review can be found in Ambec and Barla (2006), and Ambec and Lanoie (2008).

R&D expenditures (an increase of 0.15% in R&D expenditures for a pollution abatement cost increase of 1%), but no statistically significant link with the number of patents. Also drawing upon U.S. data, but restricting themselves to environmentally-related patents granted, Brunnermeier and Cohen (2003) found a positive but small relationship with environmental regulation. Both studies suggest a weak but positive link between a more stringent environmental policy regimes and the firm's innovation policy. Popp (2006) provides evidence that the introduction of environmental regulation on sulphur dioxide in the U.S., and on nitrogen dioxides in Germany and Japan, was shortly followed by a very significant increase in the number of relevant patents. In a panel study of OECD countries, Johnstone et al. (2010) found that the introduction of different policies (e.g. feed-in tariffs, renewable energy credits) have a positive impact on patenting of renewable energy technologies.

Porter is not very precise about what he means by innovation; investments can be a perceived as a proxy of how companies integrate new technology. In this vein, two studies find a negative relationship between environmental regulations and investment in physical capital. Nelson et al. (1993) found that air pollution regulations significantly increased the age of capital in U.S. electric utilities in the 1970s, with the age of capital assumed to be negatively related with environmental performance. According to Gray and Shadbegian (1998, 2003), more stringent air and water regulations have a significant impact on U.S. paper mills' investment decisions, encouraging investment in 'cleaner' production technologies. However, their results suggest that such investment tends to divert from productive investment, reducing productivity. This is consistent with the standard paradigm.

The second set of studies, which focuses on the effects of regulation on productivity, has a long tradition in the economic literature (see Jaffe et al., 1995, for a review). Most papers reviewed in Jaffe et al. (1995) highlight a negative impact of environmental regulation on productivity. For instance, Gallop and Robert (1983) estimated that SO_2 regulations slowed down productivity growth in the U.S. in the seventies by 43%. More recent papers find positive results more in line with the "strong" version. For example, Berman and Bui (2001) report that refineries located in the Los Angeles area enjoyed a significantly higher productivity than other U.S. refineries despite a more stringent air pollution regulation in this area. Similarly, Alpay et al. (2002) estimated the productivity of the Mexican food processing industry to be increasing with the severity of environmental regulation. They therefore suggest that more stringent regulation is not always detrimental to productivity.

Since market instruments have not been widely used so far, no study has been able to conduct a direct test of the "narrow" version of PH, which hypothesises that market-based instruments are more likely than traditional "command-and control" measures to induce environmental innovation. However, Burtraw (2000) provides indirect support showing that the change in environmental regulation for SO_2 emissions in the U.S. from a technology-based standard with emission caps to an emission allowance trading program in 1990, considerably reduced compliance costs (40% to 140% lower than projected). In addition, Burtraw shows that the policy change not only encouraged innovation with respect to fuel blending and scrubber efficiency, but also fostered organisational change and competition on upstream input markets.

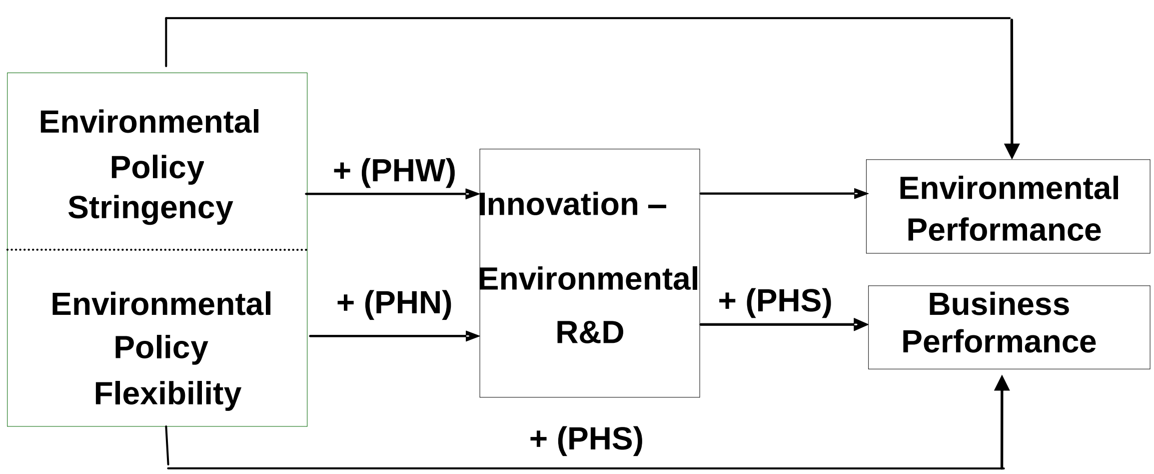
Furthermore, a number of papers have emerged from the OECD project from which the data for this paper is drawn, three of them being more closely related to our research agenda. First, Arimura et al. (2007a) use a bivariate probit model to examine the link between the stringency of environmental policies and environmental R&D, in which the second dependent variable reflects whether or not a facility has put in place an environmental accounting system. They find that overall perceived stringency is associated with more environmental research, but find no specific influence for any of the individual policy instruments available (technology-based standards, performance-based standards, pollution taxes, etc.). However, applying a different model, Johnstone and Labonne (2006) find some evidence for the role of environmentally related taxes in supporting investments in environmental R&D, while technology-based standards have a negative impact. Third, Darnall et al. (2007) also use a bivariate probit to investigate the relation between environmental performance and business performance. They find that better environmental performance enhances business performance, but that stringency of the environmental policy regime still has a negative impact on business performance. They use a bivariate probit model, transforming their dependent variable into binary form, which is different than the approach adopted here. None of these studies was centered on the PH.

3. Model framework, survey instrument, and econometric strategy

The model framework

The modelling strategy adopted is motivated by our wish to test all three versions of the PH (weak, narrow and strong), and is set out in in Figure 1 below.[5]

FIGURE 1. THE PORTER HYPOTHESIS CAUSALITY CHAIN



From this framework, we see three dependent variables emerging (Environmental R&D, Environmental Performance and Business Performance) depending directly or indirectly on

[5] Porter does not exclude the possibility that environmental policy has a direct impact on environmental performance or business performance, unmediated by innovation. As such, in the figure there are arrows which pass directly from environmental policy to environmental performance and business performance.

environmental policy. In order to test the weak version of the Porter Hypothesis (PHW), we are interested in knowing whether the effect of environmental policy stringency on 'innovation' is positive. It is hypothesised that with a greater cost associated with the use of the environment, firms will seek to innovate in a manner which saves on its use. In order to test the narrow version of the Porter Hypothesis (PHN), we need to assess the extent to which more 'flexible' policy instruments have a greater effect on innovation than more 'prescriptive' policy instruments (for a given level of policy stringency). With 'prescriptive' policies, firms have little incentive to identify the most efficient way to meet a given environmental objective, whereas more flexible instruments provide incentives for 'search'. Firms will capture some of the benefits associated with developing technologies which reduce the cost of mitigating environmental impacts. 'Flexible' instruments include most market-based instruments (such as environmental taxes and tradable permits) and performance standards, while technology-based standards are more prescriptive. And finally, in order to test the strong version of Porter Hypothesis (PHS), we assess the net effects of environmental policy stringency (and policy design) on business financial performance. The effect of environmental policy on business financial performance may be direct (e.g. in terms of compliance costs), or indirect (e.g. through the impact on innovation and thus production costs) [6].

However, environmental policy is, of course, not the only (or even perhaps the most important) factor which affects environmental R&D. For instance, the location of the facility and the sector to which it belongs may affect opportunities and incentives for investment in environmental R&D. Those sectors using more advanced technologies may be more likely to invest in R&D (and environmental R&D), irrespective of the policy regime. Facility size, measured in term of number of employees, may affect the likelihood of investing in environmental R&D. In the Schumpeterian view, it is expected that larger facilities are more likely to do research and thus satisfy PHW, but that this relation may be non-

[6] As mentioned above, if environmental regulations do increase environmental investment, some of this investment may be diverted from productivity to abatement (Gray and Shadbegian, 2003).

linear (see Jaumotte and Pain 2005 for a review). Organizational inertia and inefficiencies due to asymmetric information are expected to be stronger in larger facilities which, in line with Porter's arguments and Ambec and Barla (2002), favour the strong version of the PH, and therefore improved business performance.

Furthermore, economic theory has ambiguous predictions concerning the impact of market concentration on innovation. The Schumpeterian view predicts that facilities in more concentrated industries are more likely to invest in research since they can enjoy the monopoly rents from any innovations identified as a consequence of the R&D[7]. In contrast, in the Arrowian view, firms which enjoy market power tend "to rest on their laurels" (e.g., Tirole, 1989), which leads to the opposite prediction. Higher market concentration suggests imperfect competition in the sector which, following Simpson and Bradford (1996), might provide an economic foundation to PHS and thus better business performance.

The characteristics of the firm to which the facility belongs may also affect the propensity of the firm to invest in environmental R&D (and thus PHW), as well as the strong version of the PH. For instance, it is expected that facilities in multi-facility firms are more likely to invest in research on environmental R&D because of the potential spillovers across plants. Symmetrically, R&D investment in other plants might be beneficial to the surveyed facilities which might improve both environmental and business performance at low cost. However, if there is specialisation within the firm, the likelihood that any single facility invests in environmental R&D may be lower, and as such the expected effect of multi-facility on environmental R&D may be ambiguous. It has been hypothesised that facilities that are part of multinational firms are more likely to be concerned with environmental

[7] As suggested by a referee, the Schumpeter view of innovation would seem to depend on whether pollution abatement equipment comes from within the industry or from outside firms. Popp et al. (2008) give data on the assignee (owner) of 'environmental' patents in the pulp and paper sector, with approximately equal proportions coming from the sector itself, the chemicals sector, and the capital equipment sector.

issues for reputational reasons, and to take concrete actions, such as devoting a specific budget to environmental R&D. They might also exploit or market environmental-friendly technologies in a first-mover position which might lead to higher business performance. In addition, it is expected that facilities which are part of firms which are listed on the stock exchange may be more likely to invest in R&D (including environmental R&D) due to the difficulties of financing such investments in general. On the other hand, firms that are not listed might have less risk diversification opportunities, which make them more risk-averse in their investment decision following Kennedy (1994). The unlisted firms may tend to under-invest in risky but profitable business opportunities.

The characteristics of the market in which the facility competes may also affect the likelihood of investing in environmental R&D. For instance, there may be different incentives for facilities whose output is marketed to final consumers (and retailers) than other firms. Whether or not the benefits of signalling good environmental performance are greater for final good markets or business-to-business markets remains an open research question (see Johnstone and Labonne 2009, for a discussion of these issues). In addition, the spatial scope of the market is likely to have an effect on incentives for environmental innovation. It is expected that facilities with a more global market scope could gain more from a good environmental reputation and may thus be more likely to have a specific environmental R&D budget.

The preceding theoretical discussion will guide us in identifying the independent variables appearing in the environmental R&D equation to be presented below. Many of the factors which drive environmental R&D are also likely to affect environmental performance since investment in environmental R&D will often result in improved environmental performance. However, in some cases, the motivation for investment in environmental R&D may be better characterised as the attainment of equivalent environmental performance at lower cost (see below). Furthermore, the effect of some structural and market factors on the determinants of environmental R&D and performance may be different. For instance, to the extent that there are more likely to be intra-firm spillovers in the benefits of investment in R&D, the effect of being part of a multi-facility firm may have a more pronounced role in the case of facility-level environmental R&D than environmental performance. Similarly, access to capital may have a more pronounced role in the case of environmental R&D than environmental performance.

The impact of environmental policy design on business performance is likely to be less important than in the other two equations, with market and structural factors playing a much more important role. While it is beyond the scope of this paper to assess the determinants of business performance in a complete manner, it is important to re-emphasise that the survey instrument implemented collected a rich set of information which covers many of the factors which are found to be important in the literature. It is also expected that the country and industry dummies will capture a great deal of the variation in the data.

The survey

The data were 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 in early 2003. (For details on survey design and sampling method see Annex 1.) The data covers facilities with more than 50 employees in all manufacturing sectors. Relative to previous studies, the diversity in countries and sectors sampled implies a greater variation across policy frameworks, technological opportunities, and other factors, allowing for more reliable estimates of different potential determinants of environmental innovation and performance.

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. 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%.[8] Similar surveys in the environmental sphere in the countries sampled for this study often report even lower response rates. For instance, in the case of the European Commission's *European Business Environment Barometer,* response rates for Germany (12.9%), France (10.0%), and Norway (31.5%) are comparable or lower (see ISIGE 2001) to those obtained in this study.

Given the nature of the data, and due to the relatively large non-response rate, we have to assess the presence of a sample selection bias. We perform this assessment by implementing a Heckman sample selection procedure. We follow the standard procedure and assume that the set of variables which explain respondents' decision to answer or not is the set of control variables (see Davidson and McKinnon, 2003, for a comprehensive treatment of the procedure). The coefficient of the inverse Mills ratio is largely non-significant (P-Value of 0.958), which indicates that we could reasonably decide that selectivity is not a problem.

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%

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

[8] 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.

presented in somewhat aggregated form below. A comparison of the population of facilities at the two-digit level with our sample can be found at www.oecd.org/env/cpe/firms. In the case of Norway, on the basis of a 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 by sector is statistically different from that of the population. Facility size data is not available for Germany. 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. Given this caveat, comparing our French sample with Eurostat data of 2002[9], we found good representativeness in terms of industrial sectors, with the chemicals sector somewhat over-represented (11% vs. 7%), as is the basic metals sector (7% vs. 3%). There is some under-representativeness of small firms in our sample, but much less relative to other studies. For reasons of data classification, in the case of the United States, it is only possible to compare samples for firms with more than 100 employees. In this case the rubber and plastics sector is under-represented (8% vs. 13%) relative to data obtained from OECDSTAT.[10] The fabricated metals sector is also under-represented (13% vs. 22%).

Table 2: Survey Respondents by Sector and by Country

	ISIC Classification	Canada	France	Germany	Hungary	Japan	Norway	USA	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 & 36	32	12	26	27	32	49	34	212
Paper, Publishing & 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 & Fab'd 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 & Transp. Eqpmt	Sectors 34-35	23	19	32	22	113	44	37	290

9 Eurostat (2009) *Structural Business Statistics*.
10 OECD (2009) *Structural and Demographic Business Statistics Database*.

Recycling and Other	Sectors 37-39	3	2	10	29	29	1	5	79
Total		*256*	*268*	*898*	*463*	*1467*	*309*	*483*	*4144*

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. In the OECD sample, over 2500 facilities can be characterized as small or medium sized enterprises (< 250 employees). This is significant since evidence indicates that large firms are not representative of environment-related behavior for the population of firms (see Labonne/CL Conseil 2006). In addition, since regulators are increasingly targeting smaller sources, it is important that they be included in the sample.

One concern with such a survey is that, for strategic or other reasons, respondents might be inclined to report relatively better environmental performance than is in fact the case. However, this is not a shortcoming which is particular to this study. Indeed, self-reporting is typical when dealing with environmental performance data (e.g., the U.S. Environmental Protection Agency's TRI data are self-reported). Reassuringly, there is considerable variation in the data, and a fair number of respondents have reported worsening environmental performance over the course of the study period (see below).

It is difficult to corroborate the survey responses with other data sources since data of this kind is rarely collected, and when this is the case either the sample or the questions are very different. However, in the case of Canada, a comparison of responses to some of the questions with data obtained from a Statistics Canada study (*Environmental Protection Expenditures in the Business Sector*) can be found at (http://www.oecd.org/dataoecd/36/35/37265864.pdf). For instance, in the Statistics Canada study, 56% of facilities report having an EMS (Environmental Management System), while in the OECD sample, the corresponding figure is 54%. The proportion of facilities reporting ISO 14001 certification is almost identical in the two samples (19% and 18% respectively), mitigating fears of bias.

Arimura et al. (2007a and 2007b) compare the R&D expenditure and environmental performance data with data collected from other sources. For the R&D data, the Japanese sample in the OECD survey was compared with data collected as part of the *Survey of Research and Development 2002*[11], which has been conducted in Japan for more than a decade. As in the OECD study, respondents were requested to provide information on the specific objectives of their research expenditures, including environmental conservation. Among 4 312 facilities that replied to this question in the Japanese survey, 8.4% or 360 facilities reported that they had incurred environment-related research expenditures. In the OECD survey, the corresponding figure was 12%. However, since the OECD survey only covers facilities with 50 employees or more and larger facilities are more likely to invest in environmental R&D, the difference may be less than this would imply.

For the environmental performance data, responses in the Japanese sample to a question posed on changes in the use of natural resources in the OECD survey were compared with reported changes in water use in the Japanese *Census of Manufactures* (Arimura et al. 2007b). At the sectoral level, the correlation is positive and significant. Similarly, Darnall (2007), reports a chi-square test comparing sector groupings ("dirty" or "clean" sectors)[12] with the reported stringency of their environmental policy regime. The results showed that dirty sectors reported that the stringency of their environmental policy regime was greater than facilities operating in clean sectors ($p<0.0001$), therefore adding confidence to the accuracy of this important independent variable.

For the business performance variables, data on the change in production at the aggregated ISIC two-digit level was drawn from the OECD STAN database for Structural Analysis[13] and compared with the data collected on the change in the value of shipments over the period 2000-2002. The correlation

---

[11] Arimura *et al.* (2005) provide a basic review of the descriptive statistics of Japanese R&D Survey with focus on R&D activities for environmental purposes.

[12] This grouping relies on an existing taxonomy of U.S. manufacturing sectors (Mani and Wheeler, 1997; Gallagher and Ackerman, 2000).

[13] http://www.oecd.org/document/15/0,2340,en_2649_201185_1895503_1_1_1_1,00.html

(0.58) between the seventy observations for the two variables is positive and statistically significant ($p<0.0001$). The outliers are frequently those sectors for which the survey has a small number of observations. Overall, we are thus confident in the validity and representativeness of our survey.

The econometric strategy

This dataset is used to test the three variants of the Porter Hypothesis as depicted in Figure 1. This representation implies that there are three dependent variables: i) Business performance; ii) Environmental performance, and iii) Environmental R&D. Given that Environmental R&D affects the other two dependent variables, an instrumentation procedure (to be described below) is necessary. Our three estimated equations are:

(1) BUSINESS PERF. = θ_0 + θ_1 LOW STRINGENCY + θ_2 HIGH STRINGENCY + θ_3TECH-STANDARDS LOW + θ_4 TECH-STANDARDS MEDIUM+ θ_5 TECH-STANDARDS HIGH + θ_6PERF-STANDARDS LOW + θ_7 PERF-STANDARDS MEDIUM + θ_8 PERF-STANDARDS HIGH + θ_9TAX LOW + θ_{10}TAX MEDIUM + θ_{11}TAX HIGH + $\Sigma\ \theta_i$ COUNTRY$_i$ + $\Sigma\ \theta_j$ SECTOR$_j$ + θ_{28} AGE + θ_{29}LOG (EMPLOYMENT) + θ_{30} LOG (EMPLOYMENT)^2 + θ_{31} COMPETITION LOW + θ_{32} COMPETITION MEDIUM + θ_{33}MULTI-FACILITY + θ_{34}FIRM INTL + θ_{35} FIRM QUOTED + θ_{36} PRIMARY CUST + θ_{37} MARKETSCOPE LOCAL + θ_{38}MARKETSCOPE NATIONAL + θ_{39} MARKETSCOPE REGIONAL + θ_{40}FIT ENVIRONMENTAL R&D + λ_i

(2) ENVIRONMENTAL PERF. = δ_0 + δ_1 LOW STRINGENCY + δ_2 HIGH STRINGENCY + δ_3 TECH-STANDARDS LOW + δ_4 TECH-STANDARDS MEDIUM + δ_5 TECH-STANDARDS HIGH + δ_6PERF-STANDARDS LOW + δ_7 PERF-STANDARDS MEDIUM + δ_8 PERF-STANDARDS HIGH + δ_9TAX LOW + δ_{10}TAX MEDIUM + δ_{11}TAX HIGH + $\Sigma\ \delta_i$ COUNTRY$_i$ + $\Sigma\ \delta_j$ SECTOR$_j$ + δ_{28} AGE + δ_{29} LOG (EMPLOYMENT) + δ_{30} LOG (EMPLOYMENT)^2 + δ_{31} COMPETITION LOW + δ_{32} COMPETITION MEDIUM + δ_{33}MULTI-FACILITY + δ_{34}FIRM INTL + δ_{35} FIRM QUOTED +

δ_{36} PRIMARY CUST + δ_{37} MARKETSCOPE LOCAL + δ_{38}MARKETSCOPE NATIONAL + δ_{39} MARKETSCOPE REGIONAL + δ_{41}FIT ENVIRONMENTAL R&D + η_i

(3) ENVIRONMENTAL R&D = β_0 + β_1 LOW STRINGENCY + β_2 HIGH STRINGENCY + β_3 TECH-STANDARDS LOW+ β_4 TECH-STANDARDS MEDIUM + β_5 TECH-STANDARDS HIGH + β_6PERF-STANDARDS LOW + β_7 PERF-STANDARDS MEDIUM+ β_8 PERF-STANDARDS HIGH + β_9TAX LOW + β_{10}TAX MEDIUM + β_{11}TAX HIGH + Σ β_i COUNTRY$_i$ + Σ β_j SECTOR$_j$ + β_{28} AGE + β_{29} LOG (EMPLOYMENT) + β_{30} LOG (EMPLOYMENT)^2 + β_{31}COMPETITION LOW + β_{32} COMPETITION MEDIUM + β_{33}MULTI-FACILITY + β_{34}FIRM INTL + β_{35} FIRM QUOTED + β_{36} PRIMARY CUST + β_{37} MARKETSCOPE LOCAL + β_{38}MARKETSCOPE NATIONAL + β_{39} MARKETSCOPE REGIONAL + ε_i

where the β_k, δ_k and θ_k are parameters to be estimated, and ε_i, η_i and λ_i are error terms[14]. Given the nature of the dependent variables (to be described below) and the suspected simultaneity, we use a different estimation technique for each equation: a simple Probit for the third equation, a two stage least square (2SLS) for the second equation and an instrumental variable Probit for the first equation (using Amemiya generalized least square). We assume the second error term (η_i) to follow a normal distribution, with zero mean and a variance of σ^2, and the first and the third error terms (ε_i and λ_i) to follow a normal distribution with zero mean and a variance of one.

Dependent variables

Table 3 provides the precise definition and descriptive statistics for all the variables used in the analysis. The three dependent variables are defined as follows. For the BUSINESS PERF variable, we use the answer to the following question:

[14] η_i and λ_i are, formally, the error terms of the model involving the unobserved latent variables.

How would you assess your facility's overall business performance over the last three years?

In which respondents could answer whether: revenue has been so low as to produce large losses, revenue has been insufficient to cover costs, revenue has allowed us to break even, revenue has been sufficient to make a small profit, revenue has been well in excess of costs. Our econometric strategy, which will be detailed below, asks for the use of a binary variable. Thus, BUSINESS PERF takes the value « 1 » if the answer is « revenue has been sufficient to make a small profit, revenue has been well in excess of costs » and « 0 » otherwise.

To construct the ENVIRONMENT PERF variable, we combine the answers to the two following questions for five different impact areas (i.e. use of natural resources, solid waste, wastewater, local and regional air pollutants, and global air pollutants):

> *A) How important do you consider each of the following potential negative environmental impacts from your facility's products and production processes?* (no negative impact, moderately negative impact, very negative impact, not applicable)

> *B) Has your facility experienced a change in the environmental impacts per unit of output of its products or production processes in the last three years with respect to the following?* (significant increase, increase, no change, decrease, significant decrease, not applicable)

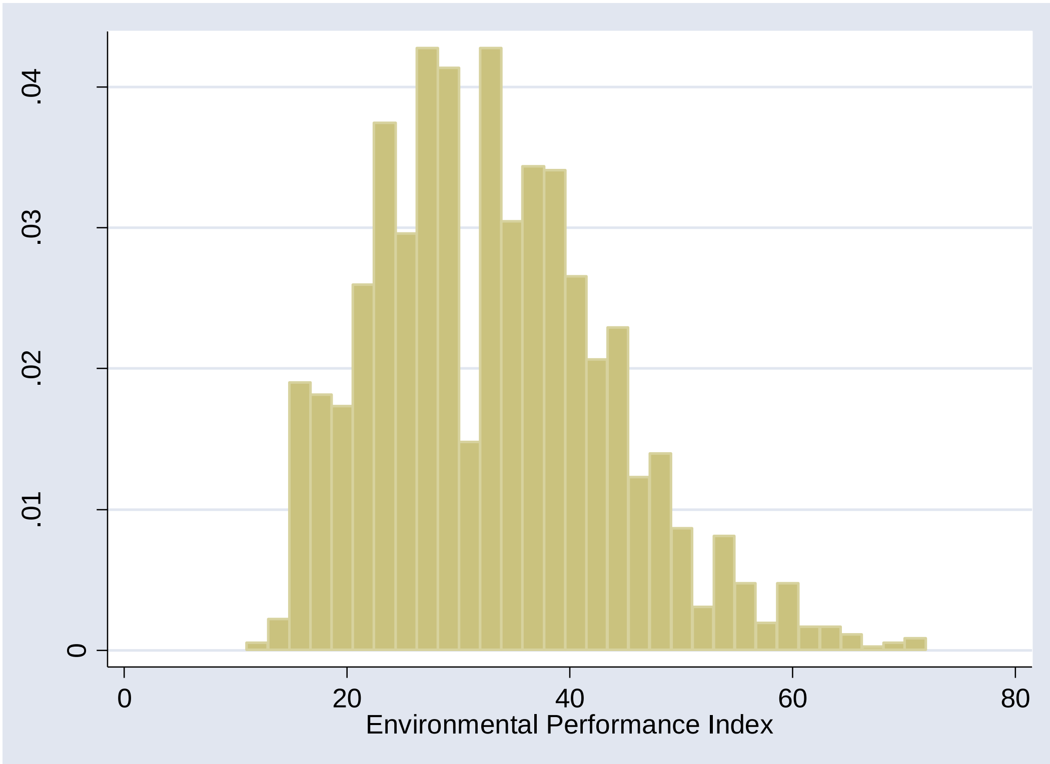
Observations from respondents who indicated that the impact area is 'not applicable' are treated as missing[15].

[15] We have also estimated the equations treating these "not applicable" as zeroes and the nature of our results was not altered. Results are available upon request.

For each type of environmental impact, we multiply the perceived "importance" of the problem (scaled from 1 to 3) and the perceived "change" (scaled from 1 to 5) that occurred in the last three years[16]. These values are then summed across the five impact areas, to give a potential maximum of 75 and minimum of 15. This procedure means that a facility which has significantly reduced emissions of a pollutant which is perceived to potentially result in an important negative impact is considered as having a better environmental performance than a facility which significantly reduced a pollutant with a moderate negative impact. In fact, our variable does measure environmental performance *per se,* but rather changes in environmental performance. The following figure provides the distribution of the ENVIRONMENTAL PERFORMANCE variable on a scale[17] from 15 to 75.

[16] The nature of our results is not altered when we use only the changes in emissions to build our environmental performance variable (results available upon request).
[17] The scale could be below 15 for facilities which reported that one or more impact areas was "not applicable".

FIGURE 2



Previous authors who have used this database (Johnstone et al, 2007b, Darnall et al., 2007) have constructed a binary variable taking the value 1 when a facility reports that there has been a "significantly decrease" or "decrease" with respect to any specific environmental impact, and 0 otherwise. As such, information with respect to the perceived potential "importance" of the impact arising out of the facility's specific production activities has not been applied. We consider our measure of environmental performance to be richer.

ENVIRONMENTAL R&D is a 0,1 variable which takes the value 1 when the respondent answered "Yes" to the following question: *Does your facility have a budget for research and development specifically related to environmental matters?,* and 0 otherwise. It would, of course, be preferable to have actual expenditures on environment-related R&D as the dependent variable, but unfortunately (and unsurprisingly) there were a large number of missing observations for this question.

For the equations (1) and (2), we use an instrument for ENVIRONMENTAL R&D because of suspected simultaneity between ENVIRONMENTAL R&D and BUSINESS PERF (as well as between ENVIRONMENTAL R&D and ENVIRONMENT PERF). Specifically, the decision to invest in environmental R&D may be influenced by unobserved factors which also affect business performance (and environmental performance): personal preferences of the manager (or the CEO), the structure of the firm, the links between the R&D department and the decision makers in the firm, etc. If this is the case, then the error term of ENVIRONMENTAL R&D may be correlated with the error term of the BUSINESS PERFORMANCE equation (λ_i) and the one of the ENVIRONMENTAL PERF equation (η_i). If this potential simultaneity problem is not addressed, we would obtain biased estimates.

As such, it is necessary to identify an instrument correlated with the decision to invest in environmental R&D, but which is not directly correlated with business performance (and accordingly for environmental performance). Once the instrument is identified, we could use it in the ENVIRONMENT PERF and the BUSINESS PERF equation. This purges the simultaneity problem. The instrument we design is the average percentage of facilities in the same sector and same country with a specific environmental R&D budget (INSTRUMENT R&D). This is assumed to be correlated with the decision to undertake environmental R&D in the specific facility (the number of "similar" firms which have adopted a specific budget may explain the decision of a specific one to adopt one), but to have an insignificant impact on the facility's business performance (the fact that a large number of "similar" firms have an environmental budget seems to represent a negligible impact on the business performance of a specific one). This type of instrument is notably used in the industrial organization literature[18] where, for instance, one wishes to explain the demand of a commodity with its price, a case in which simultaneity is likely to be present. In this case, the average price of a product on markets

[18] See Hausman et al. (1994), Hausman (1996), Nevo (2000 a, b).

different than that under consideration (i.e. neighbouring states) allows for the instrumentalisation of the price of the product, purging the simultaneity problem.

We use this instrument in the equation 2 along with a traditional 2SLS approach, and in the equation 1, along with Amemiya generalized least squares procedure. This approach provides consistent and asymptotically efficient estimators in our problem of estimating a probit with endogenous regressors (see Amemiya , 1978, and Newey, 1987).

Independent variables

Similar policy, market and structural variables are used in each of the equations. Regarding the environmental policy variables, we note first that the STRINGENCY indicators are obtained from responses to the following question:

> *How would you describe the environmental policy regime to which your facility is subject?* (1.Not particularly stringent, obligations can be met with relative ease;
>
> 2. Moderate stringency, require some managerial and technological responses; or 3.Very stringent, has a great deal of influence on decision-making in the facility)

Given that it might be considered arbitrary to apply a continuous variable with the scale 1, 2, and 3, and that perceived stringency could vary in a non-linear fashion, we constructed two dummy variables STRINGENCY LOW, which is equal to 1 if the answer is 1, and 0 otherwise; and STRINGENCY HIGH, which is equal to 1 when the answer is 3, and 0 otherwise (STRINGENCY MEDIUM is the reference case). According to PH, the sign of the estimated coefficient of STRINGENCY HIGH should be positive in the equation estimating environmental R&D (PHW), and business performance (PHS). It should also have a positive impact on environmental performance. It is expected that STRINGENCY LOW will have a negative impact in the three cases.

For four different types of environmental policy instrument (technology-based standard, performance-based standard, input tax, emission or effluent charge) respondents were requested to:

> *Please assess the following environmental policy instruments in terms of their impacts on your facility's production activities.* (1. Not important; 2. Moderately important; 3.Very important; 4. Not applicable).

In this case, "not applicable" is taken as the reference case. TECH-STANDARDS LOW is a dummy variable equal to 1 when the answer for the item "technology-based standards" are considered not important, and zero otherwise, and so on for the other two tech-standards variables (TECH-STANDARDS MEDIUM, TECH-STANDARDS HIGH) and for the PERF-STANDARDS variables. The variables TAX LOW, TAX MEDIUM and TAX HIGH are similar, but they combine the two items "input taxes", and "emission or effluent taxes or charges"[19]. With regards to the "weak version" of the PH, the more important are these policy instruments, the higher should be the probability to have a specific R&D budget allocated to environmental matters. In line with the "narrow" version of the hypothesis (PHN), we expect the more flexible tax policies to have a stronger impact than the regulatory measures (technology-based and performance-based standards) on environmental R&D. Furthermore, differentiating between regulatory measures, we expect the performance-based standards, which are more flexible, to have a stronger impact than the technology-based standards, which impose a given pollution-control technology. Actually, these technology-based standards often impose the best available technology which already exists, providing little incentive for investment in R&D.

[19] Other policy instruments were also listed in this question like subsidies/tax preference or voluntary/negotiated agreements. However, given that, in policy discussions, the focus is often put on the "command-and-control" versus "economic instruments" debate, and in order to avoid multicollinearity problems, we kept only the items mentioned above. The nature of our results is not altered when we enter the two types of taxes separately (results available upon request).

Economic analysis does not provide insights as to whether 'direct' regulations or 'market-based' instruments are more likely to induce increased efforts to improve environmental performance at the level of the individual facility. While, there are good reasons to expect that variation in environmental performance will be greater under market-based instruments than under direct regulations in the face of facility heterogeneity, the effects on performance (for a given level of policy stringency) are ambiguous. Indeed, the case for introducing market-based instruments is typically made on the basis of the cost-savings which arise out of the efficient allocation of efforts across heterogeneous facilities, not with respect to enhanced environmental effectiveness within facilities.[20] Similarly, with respect to business performance, we have no strong *a priori* assumptions. On the one hand, some market-based instruments (i.e. taxes or auctioned tradable permits) may have greater impacts on profitability than other measures in so far as the facility must finance both abatement, as well as the costs associated with 'residual' pollutants. On the other hand, the greater economic efficiency associated with the flexibility of market-based instruments may reduce compliance costs.

The 'control variables' used are the same for all three equations. They include: the sector in which the facility belongs (disaggregated into 10 classes as set out in Table 2), the log of employment (expressed in terms of full-time employee equivalents), as well as its square; the age of the facility; the number of direct competitors in the facility's primary output market classified into three classes [21]; whether or not the facility belongs to a firm with multiple facilities; whether or not the head office is located in the same country as the facility; whether or not the firm of which the facility is a part is listed on a stock exchange; the spatial scope of the market for the facility's primary output classified into four categories

[20] However, there is good reason to believe that 'cap-and-trade' permit systems will be more environmentally effective at the economy-wide level than other measures of equal stringency. See Johnstone (2005).

[21] The COMPETITION variables are obtained from responses to the following question: *With how many other firms did your facility compete on the market for its most commercially important product within the past three years? (Please tick only one box).* 1. Less than 5 ; 2. 5-10 ; 3. Greater than 10.
COMPETITION LOW is a dummy variable equal to 1 if the answer is 1 and 0 otherwise; COMPETITION MEDIUM is a dummy variable equal to 1 if the answer is 2 and 0 otherwise.

[22]. The justification for these variables and their expected signs are discussed in the section "*The model framework"* above.

[22] The MARKETSCOPE variables are obtained from responses to the question: *What best characterises the scope of your facility's market? (Please tick only one box)* 1.Local ; 2. National ; 3.Regional (neighbouring countries) ; 4. Global. MARKETSCOPE LOCAL is a dummy variable equal to 1 if the answer is 1 and 0 otherwise; MARKETSCOPE NATIONAL is a dummy variable equal to 1 if the answer is 2 and 0 otherwise; MARKETSCOPE REGIONAL is a dummy variable equal to 1 if the answer is 3 and 0 otherwise, etc.

Table 3: Descriptive statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Environmental R&D	Does facility have environmental R&D budget? (0=no; 1=yes)	0.093	0.290	0	1
Environmental Perf.	Index of environmental performance (scale= 15 to 75, see footnote 90)	33.022	10.562	11	72
Business Perf.	Assessment of overall business performance (1 if large or small profits; 0 otherwise).	0.566	0.496	0	1
Low Stringency	The environmental policy regime is not particularly stringent, obligations can be met with relative ease (0=no, 1=yes)	0.360	0.480	0	1
High Stringency	The environmental policy regime is very stringent, it has a great deal of influence on decision-making in the facility (0=no, 1=yes)	0.159	0.366	0	1
Tech-standards Low	The technology-based standards are not important (0=no, 1=yes)	0.157	0.364	0	1
Tech-standards Medium	The technology-based standards are moderately important (0=no, 1=yes)	0.355	0.478	0	1
Tech-standards High	The technology-based standards are very important (0=no, 1=yes)	0.207	0.405	0	1
Perf-standards Low	The performance-based standards are not important (0=no, 1=yes)	0.112	0.315	0	1
Perf-standards Medium	The performance-based standards are moderately important (0=no, 1=yes)	0.387	0.487	0	1
Perf-standards High	The performance-based standards are very important (0=no, 1=yes)	0.308	0.462	0	1
Tax Low	The environmental taxes are not important (0=no, 1=yes)	0.233	0.423	0	1
Tax Medium	The environmental taxes are moderately important (0=no, 1=yes)	0.475	0.499	0	1
Tax High	The environmental taxes are very important (0=no, 1=yes)	0.311	0.463	0	1
USA	Dummy for the country (omitted = Canada)	0.117	0.321	0	1
Germany	"	0.215	0.411	0	1
Hungary	"	0.111	0.315	0	1
Japan	"	0.358	0.479	0	1
France	"	0.064	0.245	0	1
Norway	"	0.074	0.262	0	1
Food	Dummy for the sector (omitted = recycling)	0.100	0.300	0	1
Leather	"	0.049	0.216	0	1
Wood	"	0.051	0.219	0	1
Pulp	"	0.079	0.270	0	1
Coke	"	0.152	0.359	0	1
Nonmetal	"	0.036	0.185	0	1
Metal	"	0.198	0.398	0	1
Machinery	"	0.238	0.426	0	1
Motor	"	0.069	0.254	0	1
Age	Age of the facility	36.135	21.582	0	99
Log (employment)	# of full time employees in facility (log)	5.106	1.047	0.6931	10.2617
Log $(employment)^2$	Squared # of full time employees in facility (log)	27.169	11.481	0.4804	105.3044
Competition Low	Number of competitors (less than 5 or not)	0.264	0.441	0	1
Competition Medium	Number of competitors (between 5 and 10 or not)	0.344	0.475	0	1
Multi-facility	Does the facility belong to a multi-facility enterprise (0=no, 1=yes)	0.520	0.500	0	1

Firm intl	Head office located in foreign country? (0=no; 1=yes)	0.120	0.325	0	1
Firm quoted	Listed on a stock exchange? (0=no; 1=yes)	0.167	0.373	0	1
Primary cust	Primary customers of the facility's products (1="Households" or "Wholesalers or retailers", 0 otherwise)	0.373	0.484	0	1
Marketscope Local	Scope of facility's market (local or not)	0.409	0.492	0	1
Marketscope National	Scope of facility's market (national or not)	0.409	0.492	0	1
Marketscope Regional	Scope of facility's market (regional or not)	0.108	0.310	0	1

5. Empirical results

Table 4 reports the estimated coefficients in our three main equations. Panel A presents the results of the Environmental R&D equation, Panel B the Environmental Performance equation, and Panel C the Business Performance equation. In each Panel, Column 1 refers to the model as presented in equations (1), (2) and (3). In order to have a sense of the robustness of our results, we also provide three alternative approaches. In each case, we define one of the three dependent variables in an alternative manner. In column (2) of each panel, we repeat the same exercise, but with total R&D expenditures as a measure of innovation generated by more rigorous environmental regulation[23]. Indeed, Porter suggests that the stringency of environmental policies should lead to more innovation, but he does not mention specifically the effect on environmental R&D. Jaffe and Palmer (1997) use total R&D expenditures in their evaluation of the PH. In column (3) of each panel, we repeat the exercise using a "0,1" measure of environmental performance, as discussed above and suggested by Darnall et al. (2007) and Johnstone et al. (2007b)[24]. Finally, in column (4) of each panel, we use the evolution of shipments

[23] As 533 facilities reported no R&D expenditures, the dependent variable is truncated and we estimate the model with a Tobit.

[24] This binary variable takes the value of 1 when a facility reports that there has been a "significantly decrease" or "decrease" with respect to any of the five specific environmental impacts, and 0 otherwise.

instead of profits as a measure of business performance. In this case, the environmental R&D and environmental performance equations are not affected.

Column (1) remains our "preferred" specification: environmental R&D is more likely to be affected by environmental policies than total R&D; our measure of environmental performance is more precise and complete than a "0,1" measure; and, profits is better approximation of business performance than sales. We will thus start our discussion by focusing on column (1).

Table 4 Estimation Results

PANEL A Environmental R&D

Dependent variable: Environmental R&D	Main Regression (1) Coeff.	P. Value	Total R&D (2) Coeff.	P.Value	Env. Perf. Binary (3) Coeff.	P. Value	Shipments (4) Coeff.	P. Value
Policy: low stringency	-0.25817	0.001	-1.57e+08	0.638	-.259839	0.001	-.259839	0.001
Policy: high stringency	0.245609	0.006	-4.62e+08	0.295	.2473861	0.006	.2473861	0.006
Tech-standards: low	0.031884	0.772	1.23e+08	0.808	.0348849	0.752	.0348849	0.752
Tech-standards: medium	-0.08279	0.405	2.85e+08	0.533	-.082071	0.409	-.082071	0.409
Tech-standards :high	0.057259	0.630	8.96e+08	0.099	.0592128	0.619	.0592128	0.619
Perf-standards : low	0.149623	0.306	1.63e+08	0.787	.1505738	0.303	.1505738	0.303
Perf-standards : medium	0.216666	0.046	7475385	0.987	.2217971	0.042	.2217971	0.042
Perf-standards :high	0.228262	0.057	-1.19e+08	0.826	.228787	0.057	.228787	0.057
Tax : low	-0.06293	0.473	-1.27e+08	0.739	-.062489	0.476	-.062489	0.476
Tax : medium	-0.02034	0.784	-1.98e+08	0.547	-.024468	0.742	-.024468	0.742
Tax : high	0.023497	0.785	2.08e+08	0.595	.0228959	0.790	.0228959	0.790
Age	0.002841	0.072	-4866450	0.483	.0027938	0.077	.0027938	0.077
Log (employment)	-0.238	0.206	-1.20e+10	0.000	-.2385036	0.205	-.2385036	0.205
Log $(employment)^2$	0.040931	0.015	1.21e+10	0.000	.0409231	0.014	.0409231	0.014
Competition : low	0.175419	0.032	-4.94e+08	0.176	.176392	0.031	.176392	0.031
Competition : medium	0.194782	0.010	-4.72e+08	0.152	.19748	0.009	.19748	0.009
Multi-facility	0.059236	0.386	-3.67e+08	0.220	.0572784	0.402	.0572784	0.402
Firm intl	-0.06321	0.543	-1.68e+08	0.744	-.0642464	0.537	-.0642464	0.537
Firm quoted	0.094056	0.283	4.41e+08	0.336	.0942427	0.283	.0942427	0.283
Primary cust	0.008214	0.911	5.53e+08	0.084	.0107136	0.884	.0107136	0.884
Marketscope : local	-0.15278	0.26	-7.32e+08	0.214	-.149377	0.270	-.149377	0.270
Marketscope : national	-0.19886	0.014	-4.91e+08	0.178	-.1979465	0.014	-.1979465	0.014
Marketscope : Regional	-0.02216	0.852	1.20e+07	0.981	-.0227915	0.848	-.0227915	0.848
R-squared	0.1146		0.1142		0.1146		0.1146	
Observations	3617		2503		3617		3617	

PANEL B Environmental Performance

Dependent variable: Environmental Perf.	Main Regression (1) Coeff.	P. Value	Total R&D (2) Coeff.	P.Value	Env. Perf. Binary (3) Coeff.	P. Value	Shipments (4) Coeff.	P. Value
Policy: low stringency	-2.86032	0.001	-2.726697	0.000	(dropped)		-2.564552	. 0.000
Policy: high stringency	2.039783	0.016	1.495629	0.037	.0117417	0.654	1.580575	0.048
Tech-standards: low	1.77132	0.049	1.93378	0.027	.0526249	0.054	1.856611	0.033
Tech-standards: medium	2.327068	0.004	2.545244	0.001	.0753608	0.002	2.38655	0.002
Tech-standards :high	1.763871	0.068	2.219477	0.031	.0365303	0.212	1.712167	0.068
Perf-standards : low	0.308034	0.822	.2480075	0.832	.0918775	0.006	.1369385	0.908
Perf-standards : medium	2.727817	0.021	2.559745	0.005	.1400523	0.000	2.55761	0.008
Perf-standards :high	4.151858	0.001	3.870746	0.000	.1667656	0.048	3.940165	0.000
Tax : low	-0.51092	0.483	-.4945114	0.461	-.0120941	0.556	-.4085853	0.546
Tax : medium	-0.1961	0.745	-.2249481	0.694	.0333386	0.054	-.0968455	0.863
Tax : high	1.196261	0.093	1.43534	0.029	.038269	0.060	.302084	0.045
Age	0.008264	0.543	.0039917	0.743	.0002143	0.586	.0047289	0.708
Log (employment)	-0.96494	0.553	-7.831466	0.174	.0359367	0.467	-.8552694	0.591
Log $(\text{employment})^2$	0.281864	0.065	.9556885	0.097	.0020351	0.677	.2438749	0.108
Competition : low	0.125763	0.858	-.3236137	0.621	.0004312	0.984	-.0777854	0.909
Competition : medium	1.074984	0.106	.6626426	0.273	.0100868	0.619	.9140179	0.158
Multi-facility	1.153022	0.038	.8177985	0.139	-.0093245	0.562	1.042265	0.050
Firm intl	0.886418	0.340	1.150229	0.134	.0105952	0.672	1.29889	0.091
Firm quoted	-0.20646	0.763	-.1538385	0.822	.0081486	0.726	-.3747591	0.578
Primary cust	-0.92137	0.093	-.7422391	0.220	-.0232598	0.169	-1.011436	0.067
Marketscope : local	-0.44737	0.714	.9556885	0.097	-.0641135	0.043	.0105878	0.992
Marketscope : national	-1.11669	0.126	-1.22517	0.065	-.0268562	0.214	-.8687797	0.216
Marketscope : Regional	0.964212	0.266	1.122838	0.179	.0127429	0.628	1.043586	0.212
Fit Env. R&D	-5.06062	0.558	-5.78e-10	0.209	.0139169	0.788	.3003784	0.850
R-squared	0.1761		0.2099		0.0990		0.2159	
Observations	1656		1656		3681		1656	

PANEL C Business Performance

Dependent variable: Business Perf.	Main Regression (1) Coeff.	P. Value	Total R&D (2) Coeff.	P.Value	Env. Perf. Binary (3) Coeff.	P. Value	Shipments (4) Coeff.	P. Value
Policy: low stringency	0.150927	0.029	.0561415	0.459	.0868955	0.223	4.99e+09	0.389
Policy: high stringency	-0.19788	0.025	-.0778881	0.257	-.1412988	0.036	-8.86e+09	0.156
Tech-standards: low	0.148977	0.092	.0505136	0.528	.0641942	0.451	-1.93e+10	0.006
Tech-standards: medium	0.064613	0.421	-.0203893	0.808	.0308771	0.750	-1.42e+10	0.008
Tech-standards :high	0.069768	0.465	-.0095498	0.919	.0302814	0.708	(dropped)	
Perf-standards : low	-0.12777	0.239	-.0907908	0.263	-.1108494	0.367	7.81e+09	0.391
Perf-standards : medium	-0.09743	0.273	-.0549574	0.519	-.0802483	0.607	3.87e+09	0.498
Perf-standards :high	-0.10547	0.300	-.083422	0.459	-.1068991	0.564	(dropped)	
Tax : low	0.065239	0.336	.0735657	0.156	0778749	0.13	5.30e+07	0.992
Tax : medium	0.041663	0.463	.0368194	0.403	.0318808	0.556	1.37e+09	0.777
Tax : high	-0.04137	0.538	-.1025273	0.093	-.0871761	0.173	4.19e+09	0.442
Age	-0.00421	0.001	-.0036149	0.000	-.0043621	0.000	-6.23e+07	0.478
Log (employment)	0.274031	0.139	.4926506	0.314	-.0154929	0.904	-2.20e+11	0.000
Log (employment)^2	-0.02785	0.157	-.0435979	0.390	.0052533	0.676	2.15e+10	0.000
Competition : low	0.109041	0.098	.2415721	0.000	.1798128	0.001	-9.78e+09	0.049
Competition : medium	0.002116	0.974	.1169826	0.017	.0562173	0.280	-7.46e+09	0.087
Multi-facility	0.056632	0.274	.0524174	0.239	.0298564	0.467	-6.83e+09	0.125
Firm intl	0.055362	0.516	.0672878	0.323	-.0871761	0.17	-4.72e+08	0.939
Firm quoted	-0.00872	0.913	0937432	0.179	.0814086	0.168	2.87e+09	0.605
Primary cust	0.044011	0.428	.0454107	0.353	.0576722	0.237	1.26e+10	0.006
Marketscope : local	-0.13881	0.176	-.0832841	0.309	-.090643	0.370	-1.17e+10	0.188
Marketscope : national	0.023562	0.735	.0606414	0.296	. 0725328	0.231	-3.05e+09	0.524
Marketscope : Regional	-0.06154	0.480	-.0671934	0.342	-.0537643	0.425	-7.94e+08	0.907
Fit R&D	0.150927	0.029	4.68e-11	0.230	.2256452	. 0.088	1.08e+09	0.855
(pseudo) R-squared			0.0504		0.0506		0.0508	
Observations	1656		3574		3574		1767	

Environmental R&D Equation

We first present our Environmental R&D equation. It is estimated using a Probit. Regarding the environmental policy variables, we first find that perceived policy stringency plays a significant role. If the environmental policy regime is perceived as "very stringent" (HIGH STRINGENCY), this has a positive and significant impact on the probability of having a specific R&D budget devoted to environmental issues. Analogously, when the regime is perceived as being "not particularly stringent" (LOW STRINGENCY), it has a negative impact.

Policy instrument choice also matters. When performance-based standards are perceived as "moderately important" or "very important" (PERF-STANDARDS MEDIUM and PERF-STANDARDS HIGH), this has a positive and significant impact on the probability of having a specific R&D budget for pollution control. None of the other policy variables has a significant coefficient.

These results provide strong support for the "weak" version of PH, but less for the "narrow" one, since flexible instruments like pollution taxes have no impact on environmental innovation. This may be simply due to the fact that these flexible instruments are not very widespread (Johnstone et al., 2007, and OECD, 2006), and that, when they are used, they are not very stringent[25] (OECD, 2006). However, the finding that performance standards have an impact, but not technology-based standards, is reassuring and in line with the "narrow version". Indeed, when technology-based standards are used, the pollution control technology to be adopted by facilities is prescribed so that, not surprisingly, they are not induced to identify other options through investment in R&D. With performance standards, facilities have more flexibility to choose how they will meet standards and thus the returns on research are potentially greater.

Among the control variables, it is noteworthy that older facilities (AGE) seem to invest more in environmental R&D, which may be due to their overall need to renew their equipment. The facilities whose market scope is national (MARKETSCOPE NATIONAL) have a lower probability to have a specific R&D budget for environmental matters than the reference case (global markets). This suggests that facilities which place emphasis on global markets may have a greater incentive to signal their willingness to improve their environmental performance. Furthermore, facilities in more concentrated markets (COMPETITION LOW, COMPETITION MEDIUM) have a higher probability to invest in research on environmental issues. This contrasts with the result in Brunnermeir and Cohen (2003), in which environmental R&D is more important in

[25] As suggested by a referee, to test this hypothesis, we have introduced interaction terms between our stringency variables and our policy types. However, none of these interaction terms was significant. Results are available upon request.

more competitive industries. However, we find no effect of facility size on the probability to have a specific environmental R&D budget.

Our results are comparable with those of Jaffe and Palmer (1997) who find a significant impact of environmental regulation on R&D expenditures, but no effect on patents. Arimura et al. (2007b) have also used this database to assess whether more stringent environmental policy regimes are associated with greater environmental innovation. They find, as in this paper, that the perceived stringency of the environmental policy regime plays a positive and significant role, but that none of the other policy variables is significant.[26]

Environmental Performance Equation

In this case, the number of observations is reduced to 1656, primarily because there are a large number of missing observations for the environmental performance question relating to "global pollutants"[27]. Given the continuous nature of the ENVIRONMENTAL PERF variable (described above) and the presence of an instrument, a 2SLS model is applied. In this equation, the variable FIT ENVIRONMENTAL R&D is the fitted value of ENVIRONMENTAL R&D while using the instrument in the first stage of the regression. The coefficient of this fitted variable is not significant. Regarding the PH, this is fairly counter-intuitive. One possible explanation could be that environmental R&D is devoted more at products than at processes, so that it could have less impact on emissions. It may also be a question of policy types. For instance, if a firm faces a specific performance standard, environmental innovation may not result in cleaner production, but rather enable it to meet the target at a lower cost[28]. However, with an environmental tax, there could be an incentive to improve the environmental performance. To test this hypothesis, we introduced interaction terms between the

[26] They use a bivariate probit model in which the other dependent variable is « environmental accounting », reflecting whether or not a facility has put in place an environmental accounting system.
[27] The nature of our results is not altered when we do not include global pollutants in our measure of environmental performance (results available upon request).
[28] See Popp (2003) for a result along these lines.

fitted environmental R&D variables and policy types, but these interaction terms were not significant[29]. Finally, the impact of R&D on environmental performance may occur with a lag, which cannot be captured with our cross-section data.

For the variables reflecting overall perceived regulatory stringency and the individual environmental policy instrument variables, most are positive and significant, suggesting, as expected, that more stringent policies improve environmental performance. Generally speaking, this is consistent with previous literature on the effectiveness of environmental policy (especially monitoring and enforcement) in reducing pollution (Magat and Viscusi, 1990; Gray and Deily, 1996; Laplante and Rilstone, 1996; Lanoie et al., 1998; Lanoie et al., 2002).

Three results are particularly noteworthy. First, when the environmental policy regime is perceived as "very stringent" (HIGH STRINGENCY), this has a positive and significant impact on environmental performance. Analogously, when the regime is perceived as "not particularly stringent" (LOW STRINGENCY), it has a negative and significant impact on environmental performance.

Second, environmental taxes have a significant impact only when they are perceived as being very important (TAX HIGH). This suggests that taxes provide incentives to reduce pollution only when they are high enough, which is not very common in OECD countries (OECD, 2006)[30]. Again, there are few comparable results in the literature given constraints on data availability.

Third, the perceived severity of the performance standards has a more important impact than that of the technology-based standards (recall that theory was ambiguous on this matter)[31]. As far as we know, this is a new

[29] Results are available upon request.
[30] As suggested by a referee, it may also be the case that taxes encourage some firms to clean up and others not to, as would be the hope with market-based policies. Thus, it may be possible for the net effect to be small, even if individual firms are cleaning up. This is particularly likely for low tax levels.
[31] A Wald test (F3, 1614) = 2.19 shows that we can reject the hypothesis that the coefficients of the performance standards are equal to those of the technology standards at the 10 % confidence level.

result in the literature since previous researchers did not have access to information detailed enough to investigate this question[32].

Among the control variables, the sector dummy variables are all negative relative to the reference sector (Recycling and other). The SIZE, the AGE, the market SCOPE and the market COMPETITION variables do not have a significant impact.

Interestingly, the fact that primary customers are primarily households and/or retailers (PRIMARY CUST), as opposed to other manufacturing firms, or other manufacturing units within the same firm, has a negative impact on reported environmental performance (at the 10 % level). This may suggest that the environmental performance is becoming more important in business-to-business (B2B) trading. For instance, facilities with ISO14001 are required to check the environmental performance of their suppliers. Actually, 43 % of the facilities reported that they pay attention to the environmental performance of their suppliers. Finally, the finding that a facility belongs to a MULTI-FACILITY firm is associated with improved environmental performance suggests that there could exist beneficial transfers of technology or expertise across facilities.

Estimates of environmental performance are included in two other papers of the OECD project (Johnstone et al., 2007b, Darnall et al., 2007). It is very difficult to compare our results with those of Johnstone et al. (2007b) since they estimate distinct equations for three types of pollutants (water, air, waste). Darnall et al. (2007) also find that regulatory influences have a positive impact on the overall environmental performance of facilities. However, they use an aggregate measure of the stringency of environmental policy regimes (issued from a factor

[32] As pointed by a referee, this result may be due to the fact that our environmental performance variable does not measure environmental performance *per se*, but rather a change in environmental performance. Thus, command-and-control regulation may quickly achieve good performance, but offers little incentives for additional improvements, while market-based regulations may provide weaker incentives for good performance, but may induce slow, gradual improvement. As asked by the referee, we have added interaction terms between stringency and policy types to show that our results hold up to alternative specifications. Our results were indeed robust, except for the environmental tax result that became insignificant in line with the argument of the referee. None of the added interaction terms was significant except the coefficient of low stringency X tax, but only at the 10 % level.

analysis), and not individual measures as we do. Furthermore, they find that facilities with an environmental R&D budget have better environmental performance but, contrary to us, they do not instrument this variable.

Business Performance Equation

The BUSINESS PERFORMANCE equation is estimated with an instrumental variable Probit (using Amemiya generalized least square). The variable FIT ENVIRONMENTAL R&D is also the fitted value of the ENVIRONMENTAL R&D while using the instrument. This variable is positive and significant. With respect to our hypothesised chain of causality, this implies that the stringency of the environmental policy regime (HIGH STRINGENCY) influences ENVIRONMENTAL R&D positively, which, in turn, has a positive effect on business performance. We compute the marginal effects of both variables in order to obtain this causality: a one-unit increase in the probability of having a more stringent policy results in a 0.037% increases in the probability for a firm to have some environmental R&D investments. Additionally, a one-unit increase in the FIT ENVIRONMENTAL R&D results in a 0.49 % increases in the probability for a firm to have a good business performance. When we multiply the two relevant coefficients, we obtain the indirect positive impact of HIGH STRINGENCY on business performance (+0.018). To our knowledge, this is the first time that these channels of influence suggested by Porter are detected empirically. However, the direct effect of HIGH STRINGENCY on business performance is negative, and the size of this effect is larger in absolute value than the positive indirect effect described above (-0.078).

In terms of the PH, one can say that innovation only partially offset the costs of complying with environmental policies, and that the strong version of PH is not valid. This may mean, for instance, that a large part of the investments necessary to comply with regulation represent additional production costs, such as through investment in end-of-pipe abatement. While some of these costs may be offset by the efficiency gains identified through investment in R&D, the net effect remains negative. This intuition is indirectly confirmed by Frondel et al. (2007) who find that the decision to invest in end-of-pipe technologies is linked to the stringency of environmental policies, while the decision to invest in integrated clean production is rather influenced by "cost savings" motivations[33]. In addition, Labonne and Johnstone (2008) find that more flexible policies are more likely to lead to the realisation of economies of scope between abatement and production, through investment in integrated abatement strategies rather than end-of-pipe solutions. No other environmental policy variable is significant.

Among the control variables, we find that American, Norwegian, German, Japanese and French facilities in the sample have a lower reported business performance than those of the reference country, Canada. The facility's AGE has a negative influence on business performance, which may suggest that older facilities have older and less productive technologies. Finally, as expected, high market concentration (LOW COMPETITION) has a positive effect on business performance (at the 10% level).

Darnall et al. (2007) also estimate a BUSINESS PERFORMANCE equation with this database using, as we saw earlier, a bivariate probit in which ENVIRONMENTAL PERFORMANCE is the second dependent variable. They find that the ENVIRONMENTAL PERFORMANCE has a positive impact on BUSINESS PERFORMANCE, although the STRINGENCY of environmental policy is found, as in our analysis, to have a negative impact on BUSINESS PERFORMANCE. The link between ENVIRONMENTAL R&D and BUSINESS PERFORMANCE is not investigated.

Regarding our robustness checks, when we use investment in general R&D as a measure of innovation induced by environmental policies (column 2), we have less support for the "weak version" of the PH. Indeed, in the R&D equation (Panel A), only the variable TECH-STANDARDS HIGH is weakly significant. The results in the Environmental Performance equation (Panel B) are largely unaffected by the change. In the Business Performance equation, the coefficient of FIT TOTAL R&D is positive as expected, but no longer significant. Interestingly, the variable HIGH STRINGENCY is no longer negative and significant, but the variable HIGH

[33] One of the questions in the questionnaire was: *«How important do you consider the following motivations to have been with respect to the environmental practices of your facility ?"* Cost savings was one of the potential items to be evaluated by the respondents.

TAX becomes negative and weakly significant indicating that, overall, environmental policies are costly in terms of business performance, which was also the conclusion in our preferred version.

When we use a “0-1” environmental performance variable (column 3), there is no change in the Environmental R&D equation, and almost no change in the Environmental Performance and Business Performance equations. Finally, when we use the evolution of shipments as a measure of business performance (column 4), the two first equations are, of course, not modified. In the Business Performance equation, the coefficient of FIT ENVIRONMENTAL R&D retains the expected positive sign, but is no longer significant. Interestingly, as in column (2), the variable HIGH STRINGENCY is no longer negative and significant, but the variable TECH-STANDARD MEDIUM becomes negative and significant again confirming the finding that environmental policy has a detrimental effect on financial performance. Overall, the results of our preferred version appear robust.

6. Concluding remarks

Overall, the richness of the data used has allowed us to assess the empirical validity of the Porter Hypothesis, through improved understanding of the channels of influence between environmental policy and business performance. In general, we find strong support for the ‘weak’ version of the hypothesis, qualified support for the ‘narrow’ version of the hypothesis, but no support for the ‘strong’ version of the hypothesis (except for the positive impact of environmental R&D on business performance). The last two sets of results have important public policy implications.

With respect to the ‘weak’ version of the hypothesis, it is reassuring to find that environmental policy induces innovation (as reflected in R&D expenditures). Indeed, it would be surprising if this were not the case. Since environmental policy changes the relative price (or opportunity cost) of environmental factors of production, it would be surprising if increased policy stringency did not encourage facilities to identify means of economising on their use.

With respect to the 'narrow' version of the hypothesis, the finding that more flexible 'performance standards' are more likely to induce innovation than more prescriptive 'technology-based standards' has important implications for public policy, and supports the trend toward 'smart regulation' found in many countries. Performance standards induce innovation by giving firms the incentive to seek out the optimal means to reduce their environmental impacts. While we do not find this to be true of market-based instruments, this may be due to the fact that, in practice, such measures are frequently applied at too low a level to induce innovation.

There is no support for the 'strong' version of the hypothesis, despite the finding that environmental policy induces investment in environmental R&D, and this, in turn, has a positive effect on business performance. However, the direct effect of environmental policy stringency on business performance is negative, and greater in size than the indirect positive effect mediated through R&D. As noted above, this may mean, for instance, that a large part of the investments necessary to comply with regulation represent additional production costs, such as through investment in end-of-pipe abatement. In terms of the PH, "innovation only partially offset the costs of complying with environmental policies"; there is no "global miracle".

Finally, some implications for businesses are noteworthy. First, since more flexible environmental policies seem to lead to more desirable outcomes, firms should put their lobbying efforts on that side. Second, even if the Porter Hypothesis cannot be generalized to the whole economy, there could be numerous "win-win" opportunities to identify. In particular, doing environmental R&D appears to be the best way to (at least partly) compensate for the costs of complying with environmental regulations. Lastly, it seems that more and more businesses are concerned by the environmental performance of their suppliers and thus, firms in B2B relationships could improve their probability to be chosen as a supplier if they improve their environmental performance.

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);
- inputs on survey design obtained from representatives of the OECD's the 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 survey did not exceed twelve pages in length and remained easily legible.

Sampling

- 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 January 7th, 2003 (see schedule below);
- additional possibility to fill in questionnaire on-line for United States survey (give web-site 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.

Schedule for Data Collection

Project Stages	Indicative Timeframe
Completion of Pre-testing by Germany, Canada, France, and Japan	Nov. 16th 2002
Final Version of Questionnaire Agreed Upon	Nov. 30rd, 2002
Translation of Questionnaire in all Languages	Dec. 20th, 2002
Questionnaires Posted by Research Teams	January 7th, 2003
Postal reminder 1	February 4th, 2003
Postal reminder 2	March 4th, 2003
Deadline for Receipt of Questionnaires from Firms	April 8th, 2003

References

Alpay, E., S. Buccola and J. Kerkvliet (2002) "Productivity growth and environmental regulation in Mexican and U.S. food manufacturing", American Journal of Agricultural Economics 84(4):887-901.

Ambec S. and P. Barla (2002), "A theoretical foundation of the Porter hypothesis", Economics Letters 75, 355-360.

Ambec, S. and P. Barla (2005) "Quand la réglementation environnementale profite aux pollueurs : survol des fondements théoriques de l'hypothèse de Porter" Working Paper GREEN, Laval University, forthcoming in L'Actualité économique.

Ambec, S. and Barla, P. (2006) "Can environmental regulations be good for business ? An assessment of the Porter hypothesis" Energy Studies Review 14, 42-62.

Ambec, S. and P. Lanoie (2008) "Does it Pay to be Green ? A Systematic Overview", Academy of Management Perspectives Vol.22 No 4, November, 45-62.

Amemiya, T., 1978, The estimation of a simultaneous equation generalized probit model, Econometrica, 46, 1193-1205.

Arimura, T., A. Hibiki and H. Katayama (2007b) 'Is a voluntary approach and effective environmental policy instrument' Resources for the Future Discussion Paper RFF 07-31.

Arimura, T., Hibiki, and A., Johnstone, N. (2007a) "An empirical study of environmental R&D: what encourages facilities to be environmentally-innovative ?" in Johnstone, N. (ed.) *Corporate Behaviour and Environmental Policy* Cheltenham UK: Edward Elgar in association with OECD.

Arimura, T.H., A. Hibiki, S. Imai and M. Sugino (2005), "Empirical analysis of the impact that environmental policy has on technologicalinnovation", Paper prepared for Final Meeting of Collaboration Projects 2004 "Sustainable economic growth and the challenges of global warming" at The Economic and Social Research Institute, Cabinet Office, Government of Japan http://www.esri.go.jp/en/prj-2004_2005/kankyou/kankyou16/syousai-e.html

Berman, E. and L.T.M. Bui (2001) "Environmental regulation and productivity: evidence from oil refineries" Review of Economics and Statistics 83(3): 498-510.

Brunnermeier, S.B. and M.A. Cohen (2003), "Determinants of environmental innovation in US manufacturing industries", Journal of Environmental Economics and Management 45: 278-293.

Burtraw, D. (2000) "Innovation under the tradable sulfur dioxide emission permits program in the U.S. electricity sector", Discussion Paper 00-38, Resources For the Future (RFF), Washington.

Darnall, N. (2007) "Environmental regulations, efficiency offsets and organizations' performance" mimeo presented at the Grenoble Conference on Environment, Innovation and Performance, June 5th.

Darnall, N. G.; Jolley, J. and Ytterhus, B. (2007) "Understanding the relationship between a facility's environmental and financial performance" in Johnstone, N. (ed.) *Corporate Behaviour and Environmental Policy* Cheltenham UK: Edward Elgar in association with OECD.

Dillman, D. (2000) *Mail and Internet Surveys: The Tailored Design Method*, John Wiley.

Frondel, M.; Horbach, J. and Rennings, K. (2007) “End-of-pipe or cleaner production ? An empirical comparison of environmental innovation decisions across OECD Countries” in Johnstone, N. (ed.) *Corporate Behaviour and Environmental Policy* Cheltenham UK: Edward Elgar in association with OECD.

Gabel, H.L. and B. Sinclair-Desgagné (2002), “The firm, its procedures, and win-win environmental regulations” in Henk Folmer et al. *Frontiers of Environmental Economics* (Cheltenham, UK).

Gallagher, K.P. and F. Ackerman (2000) *Trade Liberalization and Pollution Intensive Industry in Developing Countries: A Partial Equilibrium Approach. The Environmental Assessment of Trade Liberalization Agreements*. Paris: OECD

Gray, W.B. and R.J. Shadbegian (1998) “Environmental regulation investment timing, and technology choice”, Journal of Industrial Economics 46(2): 235-256.

Gray, W.B. and R.J. Shadbegian (2003) “Plant vintage, technology, and environmental regulation”, Journal of Environmental Economics and Management 46, 384-402.

Gray,W. and M.E. Deily (1996) “Compliance or enforcement: air pollution regulation in the U.S. steel industry” Journal of Environmental Economics and Management 31, 96-111.

Greaker, M. (2003), “Strategic environmental policy; eco-dumping or a green strategy?”, Journal of Environmental Economics and Management 45, 692-707.

Hausman, J., (1996) “Valuation of new goods under perfect and imperfect competition,” in T. Bresnahan and R. Gordon, eds., *The economics of new goods, studies in income and wealth*, Vol. 58, Chicago: National Bureau of Economic Research.

Hausman, J., G. Leonard, and J.D. Zona (1994) “Competitive Analysis with Differentiated Products,” Annales d’Economie et de Statistique, 34, 159–180.

Henriques, I., Sadorsky, P. and S. Kerekes (2007) “Environmental management systems and practices: an international perspective” in Johnstone, N. (ed.) *Corporate Behaviour and Environmental Policy* Cheltenham UK: Edward Elgar in association with OECD.

Hoffman, A. J. (2000) *Competitive Environmental Strategy: A Guide to Changing Business Landscape*. Washington: Island Press.

Institut supérieur d’ingénierie et de gestion de l'environnement (ISIGE) ‘European Business Environmental Barometer’ (2001). http://www.isige.ensmp.fr/04_isige/index.php?page=projets

Jaffe, A. B.; Peterson, S. R.; Portney, P. R. and R.N. Stavins (1995) “Environmental regulation and international competitiveness : what does the evidence tell us ? » Journal of Economic Literature 93, 12,658-12,663.

Jaffe, A.B. and K. Palmer (1997) “Environmental regulation and innovation: a panel data study” Review of Economics and Statistics 79(4): 610-619.

Japan Ministry of Internal Affairs and Communication, Statistics Bureau (2003) *Survey of Research and Development* http://www.stat.go.jp/english/data/kagaku/index.htm

Jaumotte, F. and N. Pain (2005) “From ideas to development: the determinants of R&D and patenting” OECD Economics Department Working Paper No. 457 ECO/WKP(2005)44 .

Johnstone, N. (2005) 'Tradeable permits: implications for monitoring and enforcement" in D. Helm (ed.) *Climate Change Policy* (Oxford: Oxford University Press)

Johnstone, N. and J. Labonne (2009) 'Why do manufacturing facilities introduce environmental management systems? Improving and/or signaling performance?' in *Ecological Economics*, Vol. 68, pp. 719-730.

Johnstone, N. and J. Labonne (2006) "Environmental policy, management and Research and Development" in OECD Economic Studies, Vol. 46.

Johnstone, N. I. Haščič and D. Popp (2010) 'Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts' in *Environmental and Resource Economics* (forthcoming).

Johnstone, N., Serravalle, C.; Scapecchi, P. and J. Labonne (2007a) "Public environmental policy and corporate behaviour: project background, overview of the data and summary results" in Johnstone, N. (ed.) *Corporate Behaviour and Environmental Policy* Cheltenham UK: Edward Elgar in association with OECD.

Johnstone, N.; Glachant, M.; Serravalle, C.; Riedinger, N. and P. Scapecchi (2007b) "Many a slip twixt the cup and lip: direct and indirect policy incentives to improve corporate environmental performance" in Johnstone, N. (ed.) *Corporate Behaviour and Environmental Policy* Cheltenham UK: Edward Elgar in association with OECD.

Kennedy, Peter (1994), "Innovation stochastique et coût de la réglementation environnementale," *L'Actualité économique*, vol. 70, n°2, pp 199-209.

Labonne, Julien and Johnstone, Nick (2008) "Environmental Policy and Economies of Scope in Facility-Level Environmental Practices" in *Environmental Economics and Policy Studies*, Vol. 9, No. 3, pp. 145-166.

Labonne, J. / CL Conseil (2006) 'A Comparative Analysis of the Environmental Management, Performance and Innovation of SMEs and Larger Firms' report prepared for EC DG Environment (http://ec.europa.eu/environment/sme/programme/programme_en.htm).

Lanoie, P.; Laplante, B.and J. Foulon (2002) "Incentives for pollution control : regulation or information ?" Journal of Environmental Economics and Management vol. 44, 169-187.

Lanoie, P.; Thomas, M. and J. Fearnley (1998) "Firm responses to effluent regulations : pulp and paper in Ontario, 1985-1989" Journal of Regulatory Economics 13 (1998) : 103-120.

Mani, M. and D. Wheeler (1997) "In search of pollution havens ? Dirty industry migration in the world economy" World Bank Working Paper, Washington.

Mohr R.D. (2002), "Technical change, external economies, and the Porter hypothesis", Journal of Environmental Economics and Management 43(1), 158-168.

Nelson R.A., T. Tietenberg and M.R. Donihue (1993) "Differential environmental regulation: effects on electric utility capital turnover and emissions" Review of Economics and Statistics 75(2) 368-373.

Nevo A. (2000a) "Measuring market power in the ready-to-eat cereal industry," Econometrica, 69, 307-342

Nevo A. (2000b) "Mergers with differentiated products: the case of the ready-to-eat cereal industry," Rand Journal of Economics, 31, 395-421.

Newey, W.K., 1987, Efficient estimation oflimited dependent variable models with endogenous explanatory variables, Journal of Econometrics, 36, 231-250.

Oates, E.; Palmer, K. and Portney, P. R. (1995) "Tightening environmental standards : the benefit-cost or the no-cost paradigm ?", Journal of Economic Perspectives, 9(4) 119-112.

Popp, D. (2006) "International innovation and diffusion of air pollution control Technologies: the effects of NOX and SO2 regulation in the US, Japan, and Germany", Journal of Environmental Economics and Management, 51(1), 46-71.

Popp, D. (2003) "Pollution Control Innovations and the Clean air Act of 1990", Journal of Policy Analysis and Management, 22(4), 641-660.

Popp, D.; Hafner, T.; Johnstone, N. (2008) "Policy vs. Consumer Pressure: Innovation and Diffusion of Alternative Bleaching Technologies in the Pulp Industry," in N. Johnstone and I. Haščič *Environmental Policy, Technological Innovation, and Patents* (Paris: OECD).

Porter, M. (1991) "American green strategy" Scientific American 264, 168.

Porter, M. and C. van der Linde (1995) "Towards a new conception of environment-competitiveness relationship" Journal of Economic Perspectives 9, 97-118.

Reinhardt, F.L. (2000) Down to earth: applying business principles to environmental management Boston: Harvard Business School Press

Simpson David and Robert L. Bradford (1996), "Taxing variable cost: environmental regulation as industrial policy", Journal of Environmental Economics and Management 30(3), 282-300.

Statistics Canada *Environmental protection expenditures in the business sector*, Statistics Canada http://www.statcan.ca/english/freepub/16F0006XIE/free.htm

Tirole, J. (1989) *Industrial organization*, MIT Press.

Willard, B. (2005), *The Next Sustainability Wave: Building Board-Room Buy-In.* New Society Publishers