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

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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 that includes observations from approximately 4,200 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.

1. Introduction

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, p. 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 PH 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 PH 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 **Q2** (Mohr, 2002). More precisely, when knowledge is public information, a firm does not enjoy the full return of its R&D investment that 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 PH 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 that induces it to behave as a Stackelberg leader vis-a-vis its foreign rival, thereby enjoying a first-mover advantage.[1] Alternatively, market failures may arise out of systemic organizational failures within the firm, such as

1. See also Greaker (2003) for a combination of the two market failures, namely **Q3** spillovers and market power, in the sector of pollution abatement technologies.

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 that 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. Although many researchers have tested different versions of the PH empirically, the studies are often partial and the results ambiguous (see next section below).

Given this potential for the existence of "win wins," analysis of the PH 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; Ambec and Lanoie, 2008).

Given the growing importance of environmental issues for businesses and policymakers, given the challenging and controversial nature of the PH, 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 4,200 facilities in seven OECD countries (USA, Canada, Japan, Germany, France, Hungary, and Norway). Data were 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.[2] To our knowledge, this is the first study to test all the variants of the PH 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 PH.

The rest of the paper is organized as follows. Section 2 provides a brief literature review on the empirical work related to the PH.[3] 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

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

aim is to test whether more stringent environmental policies can be commercially beneficial to the firm, that is, 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 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 (SO_2) in the United States, 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) has 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 United States in the 1970s by 43%. More recent papers find positive results more

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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.

Because 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%–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 organizational 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 are 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.
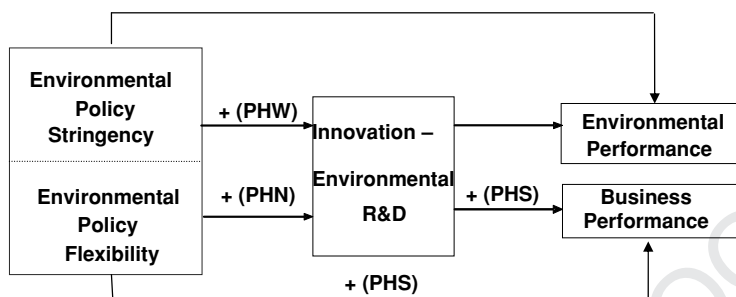
FIGURE 1. THE PORTER HYPOTHESIS CAUSALITY CHAIN

3. Model Framework, Survey Instrument, and Econometric Strategy

3.1 The Model Framework

The modeling strategy adopted is motivated by our wish to test all three versions of the PH (weak, narrow, and strong) and is set out in Figure 1 below.[4]

From this framework, we see three dependent variables emerging (Environmental R&D, Environmental Performance, and Business Performance) depending directly or indirectly on environmental policy. In order to test the weak version of the PH (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 that saves on its use. In order to test the narrow version of the PH (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 that 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,

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4. 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 that pass directly from environmental policy to environmental performance and business performance.
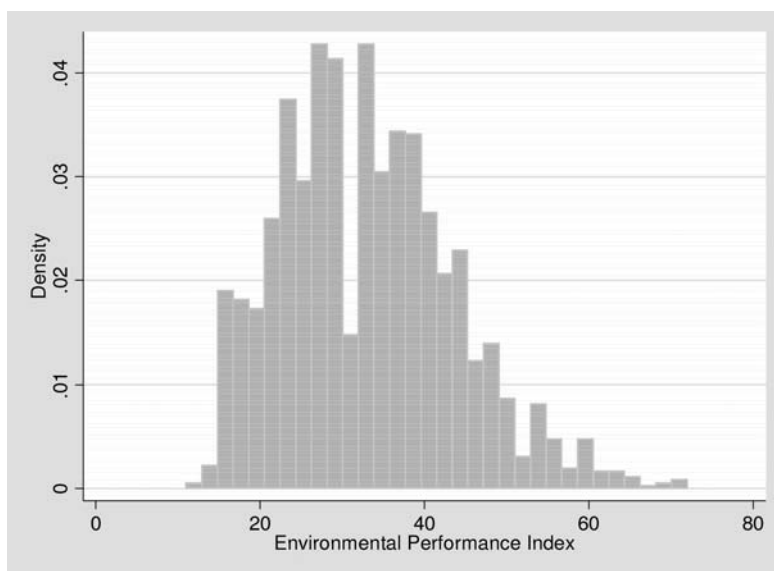
Journal of Economics and Management Strategy

FIGURE 2. DISTRIBUTION OF THE ENVIRONMENTAL PERFOR-MANCE VARIABLE   **Q5**

in order to test the strong version of PH (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).[5]

However, environmental policy is, of course, not the only (or even perhaps the most important) factor that 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 nonlinear (see Jaumotte and Pain 2005 for a review). Organizational

5. 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).

inertia and inefficiencies due to asymmetric information are expected to be stronger in larger facilities that, in line with Porter's arguments and Ambec and Barla (2002), favor 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 because they can enjoy the monopoly rents from any innovations identified as a consequence of the R&D.[6] In contrast, in the Arrowian view, firms that 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 that, 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 multifacility 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 that might improve both environmental and business performance at low cost. However, if there is specialization within the firm, the likelihood that any single facility invests in environmental R&D may be lower, and as such the expected effect of multifacility 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 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 that might lead to higher business performance. In addition, it is expected that facilities that 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

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6. 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.

risk-averse in their investment decision following Kennedy (1994). The unlisted firms may tend to underinvest 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 signaling good environmental performance are greater for final good markets or business-to-business markets remain 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 that drive environmental R&D are also likely to affect environmental performance because 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 characterized 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 intrafirm spillovers in the benefits of investment in R&D, the effect of being part of a multifacility 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. Although it is beyond the scope of this paper to assess the determinants of business performance in a complete manner, it is important to reemphasize that the survey instrument implemented collected a rich set of information that covers many of the factors that 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.

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TABLE I.

RESPONSE RATE BY COUNTRY

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	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%

3.2 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 Appendix.) The data cover 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%–35%, with a weighted mean of almost 25% (see Table I). 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%.[7] 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 nonresponse rate, we have to assess the presence of a sample selection

7. Although 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.

bias. We perform this assessment by implementing a Heckman sample selection procedure. We follow the standard procedure and assume that the set of variables that explain respondents' decision to answer or not is the set of control variables (see Davidson and McKinnon, 2003, for **Q6** a comprehensive treatment of the procedure). The coefficient of the inverse Mills ratio is largely nonsignificant (p-value of 0.958), which indicates that we could reasonably decide that selectivity is not a problem.

Table II provides data on the number of respondent facilities by industrial sector for the seven countries. Although the sectoral data are available at the ISIC two-digit level (24 sectors), the data are 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 are 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 are available when using a cutoff of 50 employees. Given this caveat, comparing our French sample with Eurostat data of 2002,[8] we found good representativeness in terms of industrial sectors, with the chemicals sector somewhat overrepresented (11% vs. 7%), as is the basic metals sector (7% vs. 3%). There is some underrepresentativeness 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 underrepresented (8% vs. 13%) relative to data obtained from OECDSTAT.[9] The fabricated metals sector is also underrepresented (13% vs. 22%).

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 2,500 facilities can be characterized as small- or medium-sized enterprises (<250 employees). This is significant because evidence indicates that large firms are not representative of environment-related behavior for the population of firms (see Labonne/CL Conseil, 2006). In addition, because regulators are increasingly targeting smaller sources, it is important that they be included in the sample.

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

TABLE II.
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 and 36	32	12	26	27	32	49	34	212
Paper, publishing and printing	Sectors 21–22	22	17	92	21	129	25	24	330
Fuel, chemicals, rubber, plastics	Sectors 23–25	40	48	149	54	195	24	126	636
Nonmetallic mineral products	Sector 26	13	13	34	21	34	14	20	149
Basic and 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 and transp. eqpmt	Sectors 34–35	23	19	32	22	113	44	37	290
Recycling and other	Sectors 37–39	3	2	10	29	29	1	5	79
Total		256	268	898	463	1,467	309	483	4,144

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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 that 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 because data of this kind are 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 Environmental Management System (EMS), 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, 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*,[10] 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 four, 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, because 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

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10. 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.

("dirty" or "clean" sectors)[11] 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 were drawn from the OECD STAN database for Structural Analysis[12] and compared with the data collected on the change in the value of shipments over the period 2000–2002. The correlation (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.

3.3 THE ECONOMETRIC STRATEGY

This dataset is used to test the three variants of the PH 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

BUSINESS PERF.

$$
\begin{aligned}
= {} & \theta_0 + \theta_1 \text{LOW STRINGENCY} + \theta_2 \text{HIGH STRINGENCY} \\
& + \theta_3 \text{TECH-STANDARDS LOW} + \theta_4 \text{TECH-STANDARDS MEDIUM} \\
& + \theta_5 \text{TECH-STANDARDS HIGH} + \theta_6 \text{PERF-STANDARDS LOW} \\
& + \theta_7 \text{PERF-STANDARDS MEDIUM} + \theta_8 \text{PERF-STANDARDS HIGH} \\
& + \theta_9 \text{TAX LOW} + \theta_{10} \text{TAX MEDIUM} + \theta_{11} \text{TAX HIGH} \\
& + \Sigma \theta_i \text{COUNTRY}_i + \Sigma \theta_j \text{SECTOR}_j + \theta_{28} \text{AGE} \\
& + \theta_{29} \text{LOG (EMPLOYMENT)} + \theta_{30} \text{LOG (EMPLOYMENT)}^2 \\
& + \theta_{31} \text{COMPETITION LOW} + \theta_{32} \text{COMPETITION MEDIUM} \\
& + \theta_{33} \text{MULTI-FACILITY} + \theta_{34} \text{FIRM INTL} + \theta_{35} \text{FIRM QUOTED} \\
& + \theta_{36} \text{PRIMARY CUST} + \theta_{37} \text{MARKETSCOPE LOCAL} \\
& + \theta_{38} \text{MARKETSCOPE NATIONAL} \\
& + \theta_{39} \text{MARKETSCOPE REGIONAL} \\
& + \theta_{40} \text{FIT ENVIRONMENTAL R\&D} + \lambda_i.
\end{aligned}
\tag{1}
$$

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

12. http://www.oecd.org/document/15/0,2340,en_2649_201185_1895503_1_1_1_1, 00.html

ENVIRONMENTAL PERF.

$\quad = \delta_0 + \delta_1\text{LOW STRINGENCY} + \delta_2\text{HIGH STRINGENCY}$

$\qquad + \delta_3\text{TECH-STANDARDS LOW}$

$\qquad + \delta_4\text{TECH-STANDARDS MEDIUM}$

$\qquad + \delta_5\text{TECH} - \text{STANDARDS HIGH} + \delta_6\text{PERF-STANDARDS LOW}$

$\qquad + \delta_7\text{PERF-STANDARDS MEDIUM} + \delta_8\text{PERF-STANDARDS HIGH}$

$\qquad + \delta_9\text{TAX LOW} + \delta_{10}\text{TAX MEDIUM} + \delta_{11}\text{TAX HIGH}$

$\qquad + \Sigma\delta_i\text{COUNTRY}_i + \Sigma\delta_j\text{SECTOR}_j + \delta_{28}\text{AGE}$

$\qquad + \delta_{29}\text{LOG (EMPLOYMENT)} + \delta_{30}\text{LOG (EMPLOYMENT)}^2$

$\qquad + \delta_{31}\text{COMPETITION LOW} + \delta_{32}\text{COMPETITIONMEDIUM}$

$\qquad + \delta_{33}\text{MULTI} - \text{FACILITY} + \delta_{34}\text{FIRM INTL} + \delta_{35}\text{FIRM QUOTED}$

$\qquad + \delta_{36}\text{PRIMARY CUST} + \delta_{37}\text{MARKETSCOPE LOCAL}$

$\qquad + \delta_{38}\text{MARKETSCOPE NATIONAL}$

$\qquad + \delta_{39}\text{MARKETSCOPE REGIONAL}$

$\qquad + \delta_{41}\text{FIT ENVIRONMENTAL R\&D} + \eta_i. \qquad\qquad (2)$

ENVIRONMENTAL R&D

$\quad = \beta_0 + \beta_1\text{LOW STRINGENCY} + \beta_2\text{HIGH STRINGENCY}$

$\qquad + \beta_3\text{TECH-STANDARDS LOW}$

$\qquad + \beta_4\text{TECH-STANDARDS MEDIUM}$

$\qquad + \beta_5\text{TECH-STANDARDS HIGH} + \beta_6\text{PERF-STANDARDS LOW}$

$\qquad + \beta_7\text{PERF-STANDARDS MEDIUM} + \beta_8\text{PERF-STANDARDS HIGH}$

$\qquad + \beta_9\text{TAX LOW} + \beta_{10}\text{TAX MEDIUM} + \beta_{11}\text{TAX HIGH}$

$\qquad + \Sigma\beta_i\text{COUNTRY}_i + \Sigma\beta_j\text{SECTOR}_j + \beta_{28}\text{AGE}$

$\qquad + \beta_{29}\text{LOG (EMPLOYMENT)} + \beta_{30}\text{LOG (EMPLOYMENT)}^2$

$\qquad + \beta_{31}\text{COMPETITION LOW} + \beta_{32}\text{COMPETITION MEDIUM}$

$\qquad + \beta_{33}\text{MULTI-FACILITY} + \beta_{34}\text{FIRM INTL} + \beta_{35}\text{FIRM QUOTED}$

$\qquad + \beta_{36}\text{PRIMARY CUST} + \beta_{37}\text{MARKETSCOPE LOCAL}$

$\qquad + \beta_{38}\text{MARKETSCOPE NATIONAL}$

$\qquad + \beta_{39}\text{MARKETSCOPE REGIONAL} + \varepsilon_i, \qquad\qquad (3)$

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.[13] 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

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

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.

3.4 Dependent Variables

Table III 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:

3.4.1 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 **Q7** 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, and 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):

(1) 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).
(2) 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.[14]

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.[15] These

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14. 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.

15. 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).

TABLE III.
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 = 15–75, 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

Continued

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TABLE III.
CONTINUED

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Variable	Description	Mean	Std. Dev.	Min	Max
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
Multifacility	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

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 that 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 that 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[16] from 15 to 75.

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 that 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 EN-VIRONMENTAL 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 that 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

16. The scale could be below 15 for facilities that reported that one or more impact areas were "not applicable."

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 that 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[17] 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 different than that under consideration (i.e., neighboring states) allows for the instrumentalization 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; Newey, 1987).

3.5 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 nonlinear 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

17. See Hausman et al. (1994), Hausman (1996), Nevo (2000 a, 2000b).

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."[18] With regard 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- 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 that already exists, providing little incentive for investment in R&D.

Economic analysis does not provide insights as to whether "direct" regulations or "market-based" instruments are more likely to induce

18. 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).

increased efforts to improve environmental performance at the level of the individual facility. Although 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 that arise out of the efficient allocation of efforts across heterogeneous facilities, not with respect to enhanced environmental effectiveness within facilities.[19] 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 II), 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;[20] 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.[21] The justification for these variables and their expected signs are discussed in the section "*The model framework*" above.

19. 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).

20. 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.

21. 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 (neighboring 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.

4. Empirical Results

Table IV 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)–(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.[22] 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).[23] Finally, in column (4) of each panel, we use the evolution of shipments 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).

4.1 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

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

23. 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.

TABLE IV.
ESTIMATION RESULTS

Panel A: Environmental R&D

Dependent Variable: Environmental R&D	Main Regression (1)		Total R&D (2)		Env. Perf. Binary (3)		Shipments (4)	
	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value
Policy: low stringency	−0.25817	0.001	-1.57×10^8	0.638	−0.259839	0.001	−0.259839	0.001
Policy: high stringency	0.245609	0.006	-4.62×10^8	0.295	0.2473861	0.006	0.2473861	0.006
Tech-standards: low	0.031884	0.772	1.23×10^8	0.808	0.0348849	0.752	0.0348849	0.752
Tech-standards: medium	−0.08279	0.405	2.85×10^8	0.533	−0.082071	0.409	−0.082071	0.409
Tech-standards: high	0.057259	0.630	8.96×10^8	0.099	0.0592128	0.619	0.0592128	0.619
Perf-standards: low	0.149623	0.306	1.63×10^8	0.787	0.1505738	0.303	0.1505738	0.303
Perf-standards: medium	0.216666	0.046	7,475,385	0.987	0.2217971	0.042	0.2217971	0.042
Perf-standards: high	0.228262	0.057	-1.19×10^8	0.826	0.228787	0.057	0.228787	0.057
Tax: low	−0.06293	0.473	-1.27×10^8	0.739	−0.062489	0.476	−0.062489	0.476
Tax: medium	−0.02034	0.784	-1.98×10^8	0.547	−0.024468	0.742	−0.024468	0.742
Tax: high	0.023497	0.785	2.08×10^8	0.595	0.0228959	0.790	0.0228959	0.790
Age	0.002841	0.072	−4,866,450	0.483	0.0027938	0.077	0.0027938	0.077
Log (employment)	−0.238	0.206	-1.20×10^{10}	0.000	−0.2385036	0.205	−0.2385036	0.205
Log (employment)^2	0.040931	0.015	1.21×10^{10}	0.000	0.0409231	0.014	0.0409231	0.014
Competition: low	0.175419	0.032	-4.94×10^8	0.176	0.176392	0.031	0.176392	0.031
Competition: medium	0.194782	0.010	$-4.72e + 08$	0.152	0.19748	0.009	0.19748	0.009
Multi-facility	0.059236	0.386	-3.67×10^8	0.220	0.0572784	0.402	0.0572784	0.402
Firm intl	−0.06321	0.543	-1.68×10^8	0.744	−0.0642464	0.537	−0.0642464	0.537
Firm quoted	0.094056	0.283	4.41×10^8	0.336	0.0942427	0.283	0.0942427	0.283
Primary cust	0.008214	0.911	5.53×10^8	0.084	0.0107136	0.884	0.0107136	0.884
Marketscope: local	−0.15278	0.26	-7.32×10^8	0.214	−0.149377	0.270	−0.149377	0.270

Continued

TABLE IV.
CONTINUED

Panel A: Environmental R&D

Dependent Variable: Environmental R&D	Main Regression (1)		Total R&D (2)		Env. Perf. Binary (3)		Shipments (4)	
	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value
Marketscope: national	−0.19886	0.014	-4.91×10^8	0.178	−0.1979465	0.014	−0.1979465	0.014
Marketscope: Regional	−0.02216	0.852	1.20×10^7	0.981	−0.0227915	0.848	−0.0227915	0.848
R^2	0.1146		0.1142		0.1146		0.1146	
Observations	3,617		2,503		3,617		3,617	

Panel B: Environmental Performance

Dependent Variable: Environmental Perf.	Main Regression (1)		Total R&D (2)		Env. Perf. Binary (3)		Shipments (4)	
	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value	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	0.0117417	0.654	1.580575	0.048
Tech-standards: low	1.77132	0.049	1.93378	0.027	0.0526249	0.054	1.856611	0.033
Tech-standards: medium	2.327068	0.004	2.545244	0.001	0.0753608	0.002	2.38655	0.002
Tech-standards: high	1.763871	0.068	2.219477	0.031	0.0365303	0.212	1.712167	0.068
Perf-standards: low	0.308034	0.822	0.2480075	0.832	0.0918775	0.006	0.1369385	0.908
Perf-standards: medium	2.727817	0.021	2.559745	0.005	0.1400523	0.000	2.55761	0.008
Perf-standards: high	4.151858	0.001	3.870746	0.000	0.1667656	0.048	3.940165	0.000
Tax: low	−0.51092	0.483	−0.4945114	0.461	−0.0120941	0.556	−0.4085853	0.546
Tax: medium	−0.1961	0.745	−0.2249481	0.694	0.0333386	0.054	−0.0968455	0.863
Tax: high	1.196261	0.093	1.43534	0.029	0.038269	0.060	0.302084	0.045

Continued

TABLE IV.
CONTINUED

Panel B: Environmental Performance

Dependent Variable: Environmental Perf.	Main Regression (1)		Total R&D (2)		Env. Perf. Binary (3)		Shipments (4)	
	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value
Age	0.008264	0.543	0.0039917	0.743	0.0002143	0.586	0.0047289	0.708
Log (employment)	−0.96494	0.553	−7.831466	0.174	0.0359367	0.467	−0.8852694	0.591
Log (employment)^2	0.281864	0.065	0.9556885	0.097	0.0020351	0.677	0.2438749	0.108
Competition: low	0.125763	0.858	−0.3236137	0.621	0.0004312	0.984	−0.0777854	0.909
Competition: medium	1.074984	0.106	0.6626426	0.273	0.0100868	0.619	0.9140179	0.158
Multi-facility	1.153022	0.038	0.8177985	0.139	−0.0093245	0.562	1.042265	0.050
Firm intl	0.886418	0.340	1.150229	0.134	0.0105952	0.672	1.29889	0.091
Firm quoted	−0.20646	0.763	−0.1538385	0.822	0.0081486	0.726	−0.3747591	0.578
Primary cust	−0.92137	0.093	−0.7422391	0.220	−0.0232598	0.169	−1.011436	0.067
Marketscope: local	−0.44737	0.714	0.9556885	0.097	−0.0641135	0.043	0.0105878	0.992
Marketscope: national	−1.11669	0.126	−1.22517	0.065	−0.0268562	0.214	−0.8687797	0.216
Marketscope: Regional	0.964212	0.266	1.122838	0.179	0.0127429	0.628	1.043586	0.212
Fit Env. R&D	−5.06062	0.558	-5.78×10^{-10}	0.209	0.0139169	0.788	0.3003784	0.850
R^2	0.1761		0.2099		0.0990		0.2159	
Observations	1,656		1,656		3,681		1,656	

Continued

TABLE IV.
CONTINUED

Panel C: Business Performance

Dependent variable: Business Perf.	Main Regression (1)		Total R&D (2)		Env. Perf. Binary (3)		Shipments (4)	
	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value
Policy: low stringency	0.150927	0.029	0.0561415	0.459	0.0868955	0.223	4.99×10^9	0.389
Policy: high stringency	−0.19788	0.025	−0.0778881	0.257	−0.1412988	0.036	-8.86×10^9	0.156
Tech-standards: low	0.148977	0.092	0.0505136	0.528	0.0641942	0.451	-1.93×10^{10}	0.006
Tech-standards: medium	0.064613	0.421	−0.0203893	0.808	0.0308771	0.750	-1.42×10^{10}	0.008
Tech-standards: high	0.069768	0.465	−0.0095498	0.919	0.0302814	0.708	(dropped)	
Perf-standards: low	−0.12777	0.239	−0.0907908	0.263	−0.1108494	0.367	7.81×10^9	0.391
Perf-standards: medium	−0.09743	0.273	−0.0549574	0.519	−0.0802483	0.607	3.87×10^9	0.498
Perf-standards: high	−0.10547	0.300	−0.083422	0.459	−0.1068991	0.564	(dropped)	
Tax: low	0.065239	0.336	0.0735657	0.156	0.0778749	0.13	5.30×10^7	0.992
Tax: medium	0.041663	0.463	0.0368194	0.403	0.0318808	0.556	1.37×10^9	0.777
Tax: high	−0.04137	0.538	−0.1025273	0.093	−0.0871761	0.173	4.19×10^9	0.442
Age	−0.00421	0.001	−0.0036149	0.000	−0.0043621	0.000	-6.23×10^7	0.478
Log (employment)	0.274031	0.139	0.4926506	0.314	−0.0154929	0.904	-2.20×10^{11}	0.000
Log (employment)^2	−0.02785	0.157	−0.0435979	0.390	0.0052533	0.676	2.15×10^{10}	0.000
Competition: low	0.109041	0.098	0.2415721	0.000	0.1798128	0.001	-9.78×10^9	0.049
Competition: medium	0.002116	0.974	0.1169826	0.017	0.0562173	0.280	-7.46×10^9	0.087
Multifacility	0.056632	0.274	0.0524174	0.239	0.0298564	0.467	-6.83×10^9	0.125
Firm intl	0.055362	0.516	0.0672878	0.323	−0.0871761	0.17	-4.72×10^8	0.939
Firm quoted	−0.00872	0.913	0.0937432	0.179	0.0814086	0.168	2.87×10^9	0.605
Primary cust	0.044011	0.428	0.0454107	0.353	0.0576722	0.237	1.26×10^{10}	0.006
Marketscope: local	−0.13881	0.176	−0.0832841	0.309	−0.090643	0.370	-1.17×10^{10}	0.188
Marketscope: national	0.023562	0.735	0.0606414	0.296	0.0725328	0.231	-3.05×10^9	0.524
Marketscope: regional	−0.06154	0.480	−0.0671934	0.342	−0.0537643	0.425	-7.94×10^8	0.907
Fit R&D	0.150927	0.029	4.68×10^{-11}	0.230	0.2256452	0.088	1.08×10^9	0.855
(pseudo) R^2			0.0504		0.0506		0.0508	
Observations	1,656		3,574		3,574		1,767	

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, because flexible instruments, such as 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 **Q8** that, when they are used, they are not very stringent[24] (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 Japanese facilities are significantly more likely to have a specific R&D budget for environmental matters than the reference country (Canada). 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 **Q9** important in 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

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24. 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.

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.[25]

4.2 Environmental Performance Equation

In this case, the number of observations is reduced to 1,656, primarily because there are a large number of missing observations for the environmental performance question relating to "global pollutants."[26] 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 counterintuitive. 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.[27] However, with an environmental tax, there could be an incentive to improve the environmental performance.[28]

For the variables reflecting overall perceived regulatory stringency and the individual environmental policy instruments 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).   **Q10**

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

25. 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.

26. 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).

27. See Popp (2003) for a result along these lines.

28. As suggested by a referee, to test this hypothesis, we introduced interaction terms between the fitted environmental R&D variable and policy types. Results were not altered and are available upon request.

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).[29] 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).[30] As far as we know, this is a new result in the literature because previous researchers did not have access to information detailed enough to investigate this question.[31]

Among the control variables, the dummy variable for Hungarian facilities is negative and significant, indicating they are less likely to report improvements in environmental performance than the reference country (Canada). For France and Japan, the variable is positive and significant. 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

29. 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.

30. 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.

31. 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.

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 MULTIFACILITY 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 (Darnall et al., 2007; Johnstone et al., 2007b). It is very difficult to compare our results with those of Johnstone et al. (2007b) because 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 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.

4.3 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. In addition, 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. Although 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.[32] In addition, Labonne and Johnstone (2008) find that more flexible policies are more likely to lead to the realization 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

32. 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.

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 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.

5. Concluding Remarks

Overall, the richness of the data used has allowed us to assess the empirical validity of the PH, 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. Because 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 economizing 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. Although 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, because more flexible environmental policies seem to lead to more desirable outcomes, firms should put their lobbying efforts on that side. Second, even if the PH 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.

Appendix

Q11

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

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

(2) inputs on survey design obtained from representatives of the OECD's the Business and Industry Advisory Committee;

(3) two-way translation from English into French, Japanese, Norwegian, German, and Hungarian;

(4) pre-tested amongst a selection of representative manufacturing facilities in Japan, Germany, and Canada;

(5) subsequent modifications to ease completion, ensuring that survey did not exceed 12 pages in length and remained easily legible.

SAMPLING

(1) Population of manufacturing facilities with 50 or more employees in seven participating countries;

(2) sample derived from universal population databases (except for United States—database of TRI facilities);

(3) stratified sampling by industrial sector (two-digit level) and by facility size (50–99; 100–249; 250–499; >500).

DATA COLLECTION

(1) Postal surveys mailed out to almost 17,000 manufacturing facilities on or around January 7, 2003 (see schedule below);

(2) additional possibility to fill in questionnaire online for U.S. survey (give web site address);

(3) accompanying letter (OECD and Departmental/University letterheads) addressed to Chief Executive Officers and/or "Environmental Managers";

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

SCHEDULE FOR DATA COLLECTION

Project Stages	Indicative Timeframe
Completion of pretesting by Germany, Canada, France, and Japan	November 16, 2002
Final version of questionnaire agreed upon	November 30, 2002
Translation of questionnaire in all languages	December 20, 2002
Questionnaires posted by research teams	January 7, 2003
Postal reminder 1	February 4, 2003
Postal reminder 2	March 4, 2003
Deadline for receipt of questionnaires from firms	April 8, 2003

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