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

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Résumé/

Jaffe et Palmer (1997) présentent trois variantes distinctes de l'hypothèse de Porter. La version « faible » de l'hypothèse suppose que la réglementation environnementale stimulera l'apparition d'innovations dans le domaine de l'environnement. La version « étroite » de l'hypothèse affirme que les réglementations environnementales flexibles donnent aux firmes une plus grande incitation pour innover que les réglementations rigides, telles que les normes prescrivant une technologie pour une industrie donnée. Enfin, la version « forte » pose qu'une réglementation correctement conçue peut induire davantage de gains en termes d'innovation que de coûts pour se conformer à la règle. Dans cet article, nous examinons la portée de ces différentes variantes de l'hypothèse de Porter en utilisant des données sur les quatre principaux éléments de la chaîne présumée de causalité (politique environnementale, recherche et développement, performance environnementale et performance commerciale). L'analyse est fondée sur une base de données unique qui inclut des observations d'approximativement 4200 établissements dans sept pays de l'OCDE. Nos résultats supportent fortement la version « faible », mais de façon plus mitigée les versions « étroite » et « forte ».

Mots clés : hypothèse de Porter, politique environnementale, innovation, performance environnementale, performance financière.

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 certain kinds of 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 is based upon a unique 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, and qualified support for the "strong" version as well.

Keywords: *Porter hypothesis, environmental policy, innovation, environmental performance, business performance.*

Codes JEL : L21, M14, Q52, Q55, Q58

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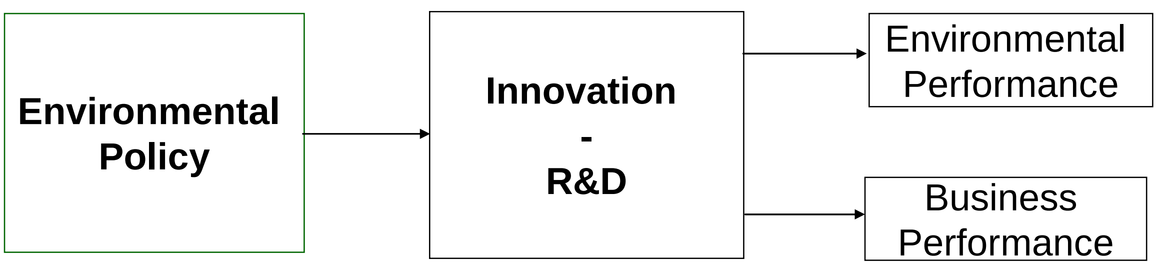
1. Introduction

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 and costs at the same time, resulting in "win-win" situations, contrary to the traditional paradigm. This line of reasoning can be represented by the following diagram:

FIGURE 1



The Porter Hypothesis is controversial. First, the evidence initially provided in its support is based on 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 could identify them by themselves without the help of the government (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), or market power (Simpson and Bradford, 1996, Greaker, 2003). Alternatively, they may arise out of systemic organisational failures within the firm, such as contractual incompleteness (Ambec and Barla, 2005), asymmetric information (Ambec and Barla, 2002), and agency control problems (Gabel and Sinclair-Desgagné 2002).

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 compensate for the cost of compliance. While many researchers have tested different versions of the Porter Hypothesis empirically, the studies are often partial and the results ambiguous (see next section below).

Given the growing importance of environmental issues in public policy, the challenging and controversial nature of the Porter Hypothesis, and the mitigated nature of the empirical results obtained thus far, assessment of the hypotheses remains an 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 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[1]. 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). This allows us to

[1] Johnstone at al. (2007a) discuss the background of the project, and present an overview of the data.

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. A more complete review can be found in Ambec and Barla (2006), Ambec and Lanoie (2007). 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 policy and technological choice, as measured by investment in R&D, in capital and new technologies, or successful patent applications. These studies test the first premise of the Porter Hypothesis that more stringent environmental regulations enhance innovation, or the "weak" version. None of them really present information on the "narrow" version of the PH, although some of them provide indirect evidence in this area as well, as will be discussed below. In the second set, 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. Yet 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 total R&D expenditures and the number of successful patent applications on pollution abatement costs (a proxy for the stringency of environmental regulation) 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 successful patents, 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. Arimura et al. (2007a) found a positive and significant relationship between environmental regulation stringency and the probability of investing in environmental R&D.

Interestingly, in the same vein, two studies find a negative relationship between environmental regulations and investment in 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 paper mills' technological choice in the U.S. However, their results suggest that it tends to divert investment from productivity to abatement, consistent with the standard paradigm.

The second set of studies, which focuses on the effects of regulation on productivity, has a long tradition in 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 pressure of environmental regulation. They therefore suggest that a more stringent regulation is not always detrimental to productivity[2].

[2] Lanoie et al. (2005) also find positive results when they use a "lagged" regulation variable instead of a contemporaneous one.

As mentioned above, due to data availability, 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). It not only encouraged innovation, but also fostered organisational change and competition on upstream input markets. The program was progressive, with permits falling from 2.5 pounds SO_2 per Btu of head input in 1995 to 1.2 in 2000, with a banking system. Firms took advantage of relatively low-cost compliance options in the early years of the program to bank allowances and, therefore, smoothed their abatement costs over time. A popular strategy was a switch to the use of coal with lower sulphur content. This resulted in more intense competition in the markets for high-sulphur and low-sulphur coal, which reduced the price of inputs. The industry also experienced technological innovation with respect to fuel blending and in the scrubber market. The former "command-and-control" regulations had not provided incentives to increase SO_2 removal by scrubbers by more than the 90% or 70% prescribed in the standard. With the new program, there were incentives for further upgrading of scrubber efficiency.

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.

3. Empirical model, econometric strategy and data

The database

The data was collected by means of a postal survey undertaken in seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway and the United States) at the facility level in early 2003 (see www.oecd.org/env/cpe/firms for a discussion of sampling procedure and survey protocol). The data covers facilities with more than 50 employees in all manufacturing sectors. The diversity in countries and sectors sampled implies a greater variation across policy frameworks, technological opportunities, and other factors which will allow for the generation of more reliable estimates of different potential determinants of environmental innovation 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, particularly since previous industrial surveys undertaken in the environmental sphere in many of the countries included in the survey have tended to have very low response rates. For instance, in a review of 183 studies based on business surveys published in academic journals Paxson (cited in Dillman, 2000) reports an average response rate of 21%.[3]

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

Table 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 presented in somewhat aggregated form below. A comparison of the population of facilities at the two-digit level with our sample for five of the seven countries 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 is statistically different from that of the population by sector. 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.

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
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, a significant shortcoming as regulators increasingly seek to influence the behaviour of smaller sources. In the sample, over 2500 facilities can be characterized as small or medium sized enterprises (< 250 employees).

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., 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*[4], 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

[4] 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.

purposes of the research expenditures, including environmental conservation. Among 4 312 facilities which replied to this question in the Japanese survey, 8.4% or 360 facilities had environment related research expenditure. 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 between the two figures 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)[5] 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 very important independent variable.

For the business performance variables, data on the change in production at the ISIC two-digit level was drawn from the OECD STAN database for Structural Analysis[6] and compared this with the data collected on the change in the value of shipments over the period 2000-2002. The correlation between the two variables is positive and significant in all cases, with correlation coefficients in excess of 0.6 for five of seven countries. The outliers are frequently those sectors for which the survey has a small number of observations.

The model and the econometric strategy

Following the representation of the Porter hypothesis depicted in Figure 1, the three "versions" will be tested by estimating the following three equations, using a two-stage estimation

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[5] This grouping relies on an existing taxonomy of U.S. manufacturing sectors (Mani and Wheeler, 1997; Gallagher and Ackerman, 2000).
[6] http://www.oecd.org/document/15/0,2340,en_2649_201185_1895503_1_1_1_1,00.html

procedure with proper instruments: i) an Environmental R&D equation; ii) an Environmental performance equation, and iii) a Business performance equation.

(1) ENVIRONMENTAL R&D = β_0 + β_1 STRINGENCY1 + β_2 STRINGENCY3 + β_3 TECH-STANDARDS1 + β_4 TECH-STANDARDS2 + β_5 TECH-STANDARDS3 + β_6PERF-STANDARDS1 + β_7 PERF-STANDARDS2 + β_8 PERF-STANDARDS3 + β_9TAX1 + β_{10}TAX2 + β_{11}TAX3 + Σ β_i COUNTRY$_i$ + Σ β_j SECTOR$_j$ + β_{28} AGE + β_{29} LOG (EMPLOYMENT) + β_{30} LOG (EMPLOYMENT)^2 + β_{31}CONCENTRATION1 + β_{32}CONCENTRATION2 + β_{33}MULTI-FACILITY + β_{34}FIRM INTL + β_{35} FIRM QUOTED + β_{36} PRIMARY CUST + β_{37} MARKETSCOPE1 + β_{38}MARKETSCOPE2 + β_{39} MARKETSCOPE3 + β_{40} INSTRUMENT R&D + ε_i

(2) ENVIRONMENTAL PERF. = δ_0 + δ_1 STRINGENCY1 + δ_2 STRINGENCY3 + δ_3 TECH-STANDARDS1 + δ_4 TECH-STANDARDS2 + δ_5 TECH-STANDARDS3 + δ_6PERF-STANDARDS1 + δ_7 PERF-STANDARDS2 + δ_8 PERF-STANDARDS3 + δ_9TAX1 + δ_{10}TAX2 + δ_{11}TAX3 + Σ δ_i COUNTRY$_i$ + Σ δ_j SECTOR$_j$ + δ_{28} AGE + δ_{29} LOG (EMPLOYMENT) + δ_{30} LOG (EMPLOYMENT)^2 + δ_{31}CONCENTRATION1 + δ_{32}CONCENTRATION2 + δ_{33}MULTI-FACILITY + δ_{34}FIRM INTL + δ_{35} FIRM QUOTED + δ_{36} PRIMARY CUST + δ_{37} MARKETSCOPE1 + δ_{38}MARKETSCOPE2 + δ_{39} MARKETSCOPE3 + δ_{40} INSTRUMENT ENV PERF + δ_{41}FIT ENVIRONMENTAL R&D + η_i

(3) BUSINESS PERF. = θ_0 + θ_1 STRINGENCY1 + θ_2 STRINGENCY3 + θ_3TECH-STANDARDS1 + θ_4 TECH-STANDARDS2 + θ_5 TECH-STANDARDS3 + θ_6PERF-STANDARDS1 + θ_7 PERF-STANDARDS2 + θ_8 PERF-STANDARDS3 + θ_9TAX1 + θ_{10}TAX2 + θ_{11}TAX3 + Σ θ_i COUNTRY$_i$ + Σ θ_j SECTOR$_j$ + θ_{28} AGE + θ_{29}LOG (EMPLOYMENT) + θ_{30} LOG (EMPLOYMENT)^2 + θ_{31}CONCENTRATION1 + θ_{32}CONCENTRATION2 + θ_{33}MULTI-FACILITY + θ_{34}FIRM INTL + θ_{35} FIRM QUOTED + θ_{36} PRIMARY CUST + θ_{37} MARKETSCOPE1 + θ_{38}MARKETSCOPE2 + θ_{39} MARKETSCOPE3 + θ_{40}FIT ENVIRONMENTAL R&D + θ_{41}FIT ENVIRONMENTAL PERF + λ_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: $\varepsilon_i \sim N(0, \sigma^2)$, $\eta_i \sim N(0, 1)$. and $\lambda_i \sim N(0, 1)$[7].

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

Dependent variables

Table 3 provides the definition and descriptive statistics for all the variables used in the analysis. The three **dependent variables** are defined as follows. 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.

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):

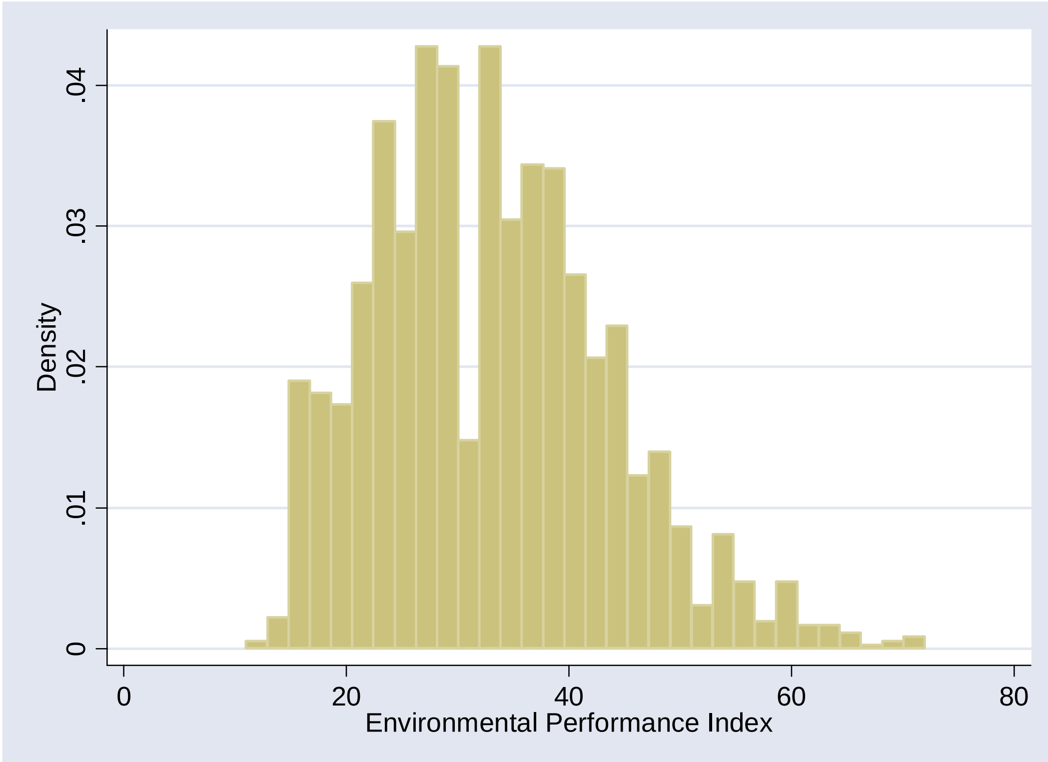
> *A) How important do you consider each of the following potential* ***negative environmental impacts*** *from your facility's products and production processes?* (no negative impact, moderately negative impact, very negative impact, not applicable)
>
> *B) Has your facility experienced a change in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

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. These values are then summed across the five impact areas, to give a potential maximum of 75 and minimum of 15. The following figure provides the distribution the ENVIRONMENTAL PERFORMANCE variable on a scale[8] from 15 to 75.

[8] 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 a 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.

For the BUSINESS PERF variable, we use the answer, on a five-point scale, to the following question:

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

Given the nature of these three dependent variables, equation (1) is estimated using a Probit model, equation (2) with an OLS, and equation (3) with an Ordered Probit. In addition, for the ENVIRONMENTAL R&D equation we use an instrument 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). Such factors might include the 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 the potential simultaneity between the two variables 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 environmental performance). We use the average percentage of facilities in the same sector and same country with a specific environmental R&D budget as the instrument (INSTRUMENT R&D). This is assumed to be correlated with the decision to undertake environmental R&D in the specific facility, but to have an insignificant impact on the facility's business performance. This type of instrument is common in the industrial organization literature[9] where, for instance, the average price of a product on markets different than that under consideration (i.e. neighbouring states) is widely used.

When we estimate the ENVIRONMENT PERF EQUATION, we use an instrument defined as the average environmental performance of the facilities in the same sector in the same country (INSTRUMENT ENV PERF). In this equation, FIT ENVIRONMENTAL R&D is the fitted value of the preceding equation. In the BUSINESS PERF equation, the variable FIT ENVIRONMENTAL PERF is the fitted value of the preceding equation[10], and the variable FIT ENVIRONMENTAL R&D is also the fitted value of the ENVIRONMENTAL R&D equation.

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

[10] PH does not necessarily imply that the environmental performance influences business performance, so the business performance equation was also estimated without the variable ENVIRONMENTAL PERF.

Independent variables

Environmental R&D Equation

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?*
> - Not particularly stringent, obligations can be met with relative ease
> - Moderate stringency, require some managerial and technological responses
> - 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 STRINGENCY1, which is equal to 1 if the answer is 1, and 0 otherwise; and STRINGENCY3, which is equal to 1 when the answer is 3, and 0 otherwise (STRINGENCY2 is the reference case). According to PH, the sign of the estimated coefficient of STRINGENCY3 should be positive. It is expected that STRINGENCY1 will have a negative impact.

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.* (not important, moderately important, very important, not applicable).

In this case, "not applicable" is taken as the reference case. TECH-STANDARDS1 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 and for the PERF-STANDARDS variables. The variables TAX1, TAX2 and TAX3 are similar, but they combine the two items "input taxes", and "emission or effluent taxes or charges"[11]. Again, with regards to the "weak version" of the PH, all these variables are expected to have a positive influence on the probability to have a specific R&D budget allocated to environmental matters. In line with the "narrow" version, we expect the more flexible tax policies to have a stronger impact than the regulatory measures (technology-based and performance-based standards).

Concerning the control variables, we first introduce COUNTRY and SECTOR dichotomous variables to capture unobservable specific influences related to the country or the sector of activity. The AGE of the facility is included, and its expected sign is ambiguous. On the one hand, older facilities may use older technologies, and therefore have a greater need for research and development on environmental matters. On the other hand, older facilities may face less stringent regulations than new ones, and have lower incentives to do environmental R&D. We use the EMPLOYMENT level as a proxy for the size of the facility. In the Schumpeterian view, it is expected that larger facilities are more likely to do research, but that this relation may be non-linear ($EMPLOYMENT^2$) (see Jaumotte and Pain 2005 for a review.) As in many other papers, we use these measures in log form. Standard theory has ambiguous predictions concerning the impact of market concentration on innovation (CONCENTRATION1 and CONCENTRATION2)[12]. 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. In contrast, in the Arrovian view, firms which enjoy market power tend "to rest on their laurels" (e.g., Tirole, 1989), which leads to the opposite prediction.

[11] Other policy instruments were also listed in this question like subsidies or voluntary 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.

[12] The CONCENTRATION 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.
CONCENTRATION1 is a dummy variable equal to 1 if the answer is 1 and 0 otherwise; CONCENTRATION2 is a dummy variable equal to 1 if the answer is 2 and 0 otherwise.

We also include three variables to capture important characteristics of the firm to which the facility belongs. First, the variable MULTI-FACILITY reflects whether the facility belongs to a multi-facility enterprise. It is expected that facilities in multi-facility firms are more likely to invest in research on environmental matters because of the potential spillovers across plants. Second, a variable reflects if the firm's head office is located in a foreign country (FIRM INTL), in order to test whether or not multinational firms are more likely to be concerned with environmental issues, and to take concrete actions, such as devoting a specific budget to R&D. Third, FIRM QUOTED reflects whether or not a facility belongs to a company quoted on the stock market. It is expected that firms on the stock exchange are more likely to signal their concern for environmental matters to potential investors. In addition, due to the difficulties frequently encountered in financing R&D, a stock market listing may ease some of the constraints.

Finally, we include variables to reflect the characteristics of the facility's market. The first one, PRIMARY CUST is equal to 1 when the primary customers of the facility's products are "households" or "wholesalers or retailers", and 0 otherwise. In the same vein as with the preceding variable, it is expected that facilities who deal directly with customers or retailers may have greater incentive to signal their actions related to environmental issues. We also have three variables to capture the spatial scope of the market in which they operate (MARKETSCOPE1, MARKETSCOPE2, MARKETSCOPE3)[13]. It is expected that facilities with a more global market scope are more likely to have a specific environmental R&D budget.

Environmental Performance Equation

In this equation, we have the same independent variables, except for the instrument, and for the FIT ENVIRONMENTAL R&D variable, which is the fitted value of the preceding equation. This variable is expected to positively influence environmental performance. Regarding the expected signs of the other independent variables, we postulate that the same

[13] 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. MARKETSCOPE2 is a dummy variable equal to 1 if the answer is 2 and 0 otherwise;MARKETSCOPE3 is a dummy variable equal to 1 if the answer is 3 and 0 otherwise, etc.

arguments prevailing in the preceding equation are relevant, i.e., variables influencing positively the probability to have a specific environmental R&D budget are likely to influence positively the environmental performance. Regarding the environmental policy variables, 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. In the face of facility heterogeneity, there are nevertheless good reasons to expect that variation in environmental performance will be greater under market-based instruments than under direct regulations. 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.[14]

Business Performance Equation

Here also, the same independent variables as in the preceding equation are used, except that we add the variable FIT ENVIRONMENTAL PERF. In line with Porter's argument and with results obtained in previous studies (e.g. Darnall et al., 2007), the coefficient of this variable should be positive, as well as the coefficient of the FIT ENVIRONMENTAL R&D variable. The arguments concerning the expected signs for the other independent variables are fairly intuitive. In the next section, they will be discussed in details for the variables that turn out to be significant.

[14] 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).

Table 3: Descriptive statistics for the main variables

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=revenue has been so low as to produce large losses; 2=revenue has been insufficient to cover costs; 3=revenue has allowed us to break even; 4=revenue has been sufficient to make a small profit; 5=revenue has been well in excess of costs)	3.460	0.989	1	5
Stingency1	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
Stringency3	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-standards1	The technology-based standards are not important (0=no, 1=yes)	0.157	0.364	0	1
Tech-standards2	The technology-based standards are moderately important (0=no, 1=yes)	0.355	0.478	0	1
Tech-standards3	The technology-based standards are very important (0=no, 1=yes)	0.207	0.405	0	1
Perf-standards1	The performance-based standards are not important (0=no, 1=yes)	0.112	0.315	0	1
Perf-standards2	The performance-based standards are moderately important (0=no, 1=yes)	0.387	0.487	0	1
Perf-standards3	The performance-based standards are very important (0=no, 1=yes)	0.308	0.462	0	1
Tax1	The environmental taxes are not important (0=no, 1=yes)	0.233	0.423	0	1
Tax2	The environmental taxes are moderately important (0=no, 1=yes)	0.475	0.499	0	1
Tax3	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 $(\text{employment})^2$	Squared # of full time employees in facility (log)	27.169	11.481	0.4804	105.3044
Concentration1	Number of competitors (less than 5 or not)	0.264	0.441	0	1
Concentration2	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
Marketscope1	Scope of facility's market (local or not)	0.409	0.492	0	1
Marketscope2	Scope of facility's market (national or not)	0.409	0.492	0	1
Markescope3	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[15]. 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 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). 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).

[15] Since we refer to total R&D expenditures, an OLS model is used. As 533 facilities reported no R&D expenditures, the dependent variable is truncated and we also estimated the model with a Tobit. The results (available upon request) were very similar to those reported in Table 4.

PANEL A

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
Stringency1	-.259839 0.001	-1.57e+08 0.638	-.259839 0.001	-.259839 0.001
Stringency3	.2473861 0.006	-4.62e+08 0.295	.2473861 0.006	.2473861 0.006
Tech-standards1	.0348849 0.752	1.23e+08 0.808	.0348849 0.752	.0348849 0.752
Tech-standards2	-.082071 0.409	2.85e+08 0.533	-.082071 0.409	-.082071 0.409
Tech-standards3	.0592128 0.619	8.96e+08 0.104	.0592128 0.619	.0592128 0.619
Perf-standards1	.1505738 0.303	1.63e+08 0.787	.1505738 0.303	.1505738 0.303
Perf-standards2	.2217971 0.042	7475385 40.987	.2217971 0.042	.2217971 0.042
Perf-standards3	.228787 0.057	-1.19e+08 50.826	.228787 0.057	.228787 0.057
Tax1	-.062489 0.476	-1.27e+08 0.739	-.062489 0.476	-.062489 0.476
Tax2	-.024468 0.742	-1.98e+08 0.547	-.024468 0.742	-.024468 0.742
Tax3	.0228959 0.790	2.08e+08 0.595	.0228959 0.790	.0228959 0.790
Age	.0027938 0.077	-4866450 0.483	.0027938 0.077	.0027938 0.077
Log (employment)	-.2385036 0.205	-1.20e+10 0.000	-.2385036 0.205	-.2385036 0.205
Log $(employment)^2$	.0409231 0.014	1.21e+10 0.000	.0409231 0.014	.0409231 0.014
Concentration1	.176392 0.031	-4.94e+08 0.176	.176392 0.031	.176392 0.031
Concentration2	.19748 0.009	-4.72e+08 0.152	.19748 0.009	.19748 0.009
Multi-facility	.0572784 0.402	-3.67e+08 0.220	.0572784 0.402	.0572784 0.402
Firm intl	-.0642464 0.537	-1.68e+08 0.744	-.0642464 0.537	-.0642464 0.537
Firm quoted	.0942427 0.283	4.41e+08 0.336	.0942427 0.283	.0942427 0.283
Primary cust	.0107136 0.884	5.53e+08 0.084	.0107136 0.884	.0107136 0.884
Marketscope1	-.149377 0.270	-7.32e+08 0.214	-.149377 0.270	-.149377 0.270
Marketscope2	-.1979465 0.014	-4.91e+08 0.178	-.1979465 0.014	-.1979465 0.014
Marketscope3	-.0227915 0.848	1.20e+07 0.981	-.0227915 0.848	-.0227915 0.848
Instrument R&D	4.525124 0.000	9244826 0.000	4.525124 0.000	4.525124 0.000
R-squared	0.1146	0.1142	0.1146	0.1146
Observations	3617	2503	3617	3617

PANEL B

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
Stringency1	-2.564552 . 0.000	-2.726697 0.000	(dropped)	-2.564552 . 0.000
Stringency3	1.580575 0.048	1.495629 0.037	.0117417 0.654	1.580575 0.048
Tech-standards1	1.856611 0.033	1.93378 0.027	.0526249 0.054	1.856611 0.033
Tech-standards2	2.38655 0.002	2.545244 0.001	.0753608 0.002	2.38655 0.002
Tech-standards3	1.712167 0.068	2.219477 0.031	.0365303 0.212	1.712167 0.068
Perf-standards1	.1369385 0.908	.2480075 0.832	.0918775 0.006	.1369385 0.908
Perf-standards2	2.55761 0.008	2.559745 0.005	.1400523 0.000	2.55761 0.008
Perf-standards3	3.940165 0.000	3.870746 0.000	.1667656 0.048	3.940165 0.000
Tax1	-.4085853 0.546	-.4945114 0.461	-.0120941 0.556	-.4085853 0.546
Tax2	-.0968455 0.863	-.2249481 0.694	.0333386 0.054	-.0968455 0.863
Tax3	.302084 0.045	1.43534 0.029	.038269 0.060	.302084 0.045
Age	.0047289 0.708	.0039917 0.743	.0002143 0.586	.0047289 0.708
Log (employment)	-.8552694 0.591	-7.831466 0.174	.0359367 0.467	-.8552694 0.591
Log (employment)2	.2438749 0.108	.9556885 0.097	.0020351 0.677	.2438749 0.108
Concentration1	-.0777854 0.909	-.3236137 0.621	.0004312 0.984	-.0777854 0.909
Concentration2	.9140179 0.158	.6626426 0.273	.0100868 0.619	.9140179 0.158
Multi-facility	1.042265 0.050	.8177985 0.139	-.0093245 0.562	1.042265 0.050
Firm intl	1.29889 0.091	1.150229 0.134	.0105952 0.672	1.29889 0.091
Firm quoted	-.3747591 0.578	-.1538385 0.822	.0081486 0.726	-.3747591 0.578
Primary cust	-1.011436 0.067	-.7422391 0.220	-.0232598 0.169	-1.011436 0.067
Marketscope1	.0105878 0.992	.9556885 0.097	-.0641135 0.043	.0105878 0.992
Marketscope2	-.8687797 0.216	-1.22517 0.065	-.0268562 0.214	-.8687797 0.216
Marketscope3	1.043586 0.212	1.122838 0.179	.0127429 0.628	1.043586 0.212
Instrument Env. Perf.	.3820423 0.000	2356673 0.001	.0063639 0.013	.3820423 0.000
Fit Env. R&D	.3003784 0.850	-5.78e-10 0.209	.0139169 0.788	.3003784 0.850
R-squared	0.2159	0.2099	0.0990	0.2159
Observations	1656	1656	3681	1656

PANEL C

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
Stringency1	.0869374	0.219	.0561415	0.459	.0868955	0.223	4.99e+09	0.389
Stringency3	-.1406783	0.051	-.0778881	0.257	-.1412988	0.036	-8.86e+09	0.156
Tech-standards1	.0632713	0.392	.0505136	0.528	.0641942	0.451	-1.93e+10	0.006
Tech-standards2	.0293627	0.687	-.0203893	0.808	.0308771	0.750	-1.42e+10	0.008
Tech-standards3	.0299407	0.700	-.0095498	0.919	.0302814	0.708	(dropped)	
Perf-standards1	-.1146602	0.167	-.0907908	0.263	-.1108494	0.367	7.81e+09	0.391
Perf-standards2	-.0843931	0.296	-.0549574	0.519	-.0802483	0.607	3.87e+09	0.498
Perf-standards3	-.1112005	0.279	-.083422	0.459	-.1068991	0.564	(dropped)	
Tax1	.0780998	0.130	.0735657	0.156	0778749	0.13	5.30e+07	0.992
Tax2	0303942	0.481	.0368194	0.403	.0318808	0.556	1.37e+09	0.777
Tax3	-.0878812	0.113	-.1025273	0.093	-.0871761	0.173	4.19e+09	0.442
Age	-.0043678	0.000	-.0036149	0.000	-.0043621	0.000	-6.23e+07	0.478
Log (employment)	-.0176274	0.888	.4926506	0.314	-.0154929	0.904	-2.20e+11	0.000
Log (employment)^2	.0053395	0.682	-.0435979	0.390	.0052533	0.676	2.15e+10	0.000
Concentration1	.1797393	0.001	.2415721	0.000	.1798128	0.001	-9.78e+09	0.049
Concentration2	.0564358	0.291	.1169826	0.017	.0562173	0.280	-7.46e+09	0.087
Multi-facility	.0309915	0.474	.0524174	0.239	.0298564	0.467	-6.83e+09	0.125
Firm intl	.0794885	0.235	.0672878	0.323	-.0871761	0.17	-4.72e+08	0.939
Firm quoted	.0807965	0.172	0937432	0.179	.0814086	0.168	2.87e+09	0.605
Primary cust	.0579448	0.207	.0454107	0.353	.0576722	0.237	1.26e+10	0.006
Marketscope1	.0579448	0.207	-.0832841	0.309	-.090643	0.370	-1.17e+10	0.188
Marketscope2	.0730595	0.194	.0606414	0.296	. 0725328	0.231	-3.05e+09	0.524
Marketscope3	-.0535669	0.433	-.0671934	0.342	-.0537643	0.425	-7.94e+08	0.907
Fit Env. Perf.	-.0007085	0.966	.006842	. 0.758	-.0425329	0.966	1.06e+09	0.500
Fit R&D	.2259759	0.089	4.68e-11	0.230	.2256452	. 0.088	1.08e+09	0.855
(pseudo) R-squared	0.0506		0.0504		0.0506		0.0508	
Observations	1656		3574		3574		1767	

Environmental R&D Equation

In our first equation, the dependent variable is a binary variable indicating the existence or not of a specific R&D budget for environmental matters in the facility. It is estimated using a Probit, with an instrument defined as the average percentage of facilities in the same sector and same country with a specific environmental R&D budget. This variable, INSTRUMENT R&D, has a positive and strongly significant coefficient.

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" (STRINGENCY3), 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" (STRINGENCY1), it has a negative impact on the probability to have a specific environmental R&D budget. Policy instrument choice also matters. When performance-based standards are perceived as "moderately important" or "very important" (PERF-STANDARDS2 and PERF-STANDARDS3), 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 support for the "weak" version of PH, but not for the "narrow" one, since flexible instruments like pollution taxes are not those with the strongest impact on environmental innovation. This may be simply due to the fact that these instruments are not very widespread (Johnstone et al., 2007, and OECD, 2006), and that, when they are used, they are not very stringent (OECD, 2006). However, the finding that performance standards have an impact, but not technology-based standards, is reassuring. 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. Actually, our results suggest that more “flexible” regulations (performance standards) have more impact on environmental innovation than more prescriptive measures (technology-based standards), which is in line with Porter’s narrow version.

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). The facilities whose market scope is regional (MARKETSCOPE3) have a lower probability to have a specific R&D budget for environmental matters than the reference case (local markets). This suggests that facilities which put the emphasis on their local market may have a greater incentive to signal their willingness to improve their environmental performance. Furthermore, facilities in more concentrated markets (CONCENTRATION1, CONCENTRATION2) have a higher probability to invest in research on environmental issues. This contrasts with the result in Brunnermeir and Cohen (2003) who find that environmental R&D is more 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 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. However, their econometric approach is different than ours[16].

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

[16] As we have seen, 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.

relating to “global pollutants”. Given the continuous nature of the ENVIRONMENTAL PERF variable (described above), an OLS model is applied. In this equation, an instrument is used, INTRUMENT ENV PERF, which is the average environmental performance of the facilities in the same sector in the same country. It has a positive coefficient, as expected, and it is highly significant. Furthermore, the variable FIT ENVIRONMENTAL R&D is the fitted value of the preceding equation that was estimated with a similar instrument as that just mentioned. The coefficient of this fitted variable has a positive sign, as expected, but is not significant.

Regarding the environmental policy 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 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, the perceived stringency of the performance standards has a more important impact than that of the technology-based standards as suggested by theory[17]. As far as we know, this is a new result in the literature since previous researchers did not have access to information detailed enough to investigate this question.

Second, when the environmental policy regime is perceived as “very stringent” (STRINGENCY3), this has a positive and significant impact on environmental performance. Analogously, when the regime is perceived as “not particularly stringent” (STRINGENCY1), it has a negative and significant impact on environmental performance.

Third, environmental taxes have a significant impact only when they are perceived as being very important (TAX3). This suggests that taxes provide incentives to reduce

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[17] A Wald test (F3, 1614) = 2.12 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.

pollution only when they are high enough, which is not very common in OECD countries (OECD, 2006). Again, there are few comparable results in the literature given constraints on data availability.

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 the U.S., 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 CONCENTRATION 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. 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. Finally, the finding that a facility belongs to a MULTI-FACILITY firm is associated with improved environmental performance suggests that there could be 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 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

Given the nature of the dependent variable the BUSINESS PERFORMANCE equation is estimated with an Ordered Probit model (1656 observations). The variable FIT ENVIRONMENTAL PERF is the fitted value of the preceding equation that was estimated with a proper instrument[18]. The variable FIT ENVIRONMENTAL R&D is also the fitted value of the ENVIRONMENTAL R&D equation. This variable is positive and significant (at the 10 % level). With respect to our hypothesised chain of causality, this implies that the stringency of the environmental policy regime (STRINGENCY3) influences ENVIRONMENTAL R&D positively, which, in turn, has a positive effect on business performance. When we multiply the two relevant coefficients, we obtain the **indirect** positive impact of STRINGENCY 3 on business performance (≈ +0,05). To our knowledge, this is the first time that these channels of influence suggested by Porter are detected empirically.

However, the **direct** effect of STRINGENCY 3 on business performance is negative, and the size of this effect is larger in absolute value than the positive indirect effect described above (-0,14). In terms of the PH, one can say that “innovation only partially offset the costs of complying with environmental policies”. 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[19]. No other environmental policy variable is significant, nor is the FIT ENVIRONMENTAL PERF variable.

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[18] PH does not necessarily imply that the environmental performance influences business performance, and the nature of the results was not altered without the variable FIT ENVIRONMENTAL PERF.
[19] 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.

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, strong market concentration (CONCENTRATION1) has a positive effect on business performance.

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.

Other researchers have examined the link between environmental performance and business performance with a simpler approach than that developed here, paying less attention to the role of environmental policy and environmental R&D, and making no attempt to deal with endogeneity issues (Hart and Ahuja, 1996; Russo and Fouts, 1997; Konar and Cohen, 2001). In general, they find a positive relationship between environmental performance and business performance.

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-STANDARDS3 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 STRINGENCY3 is no longer negative and significant, but the variable TAX3 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 STRINGENCY3 is no longer negative and significant, but the variable TECH STANDARD2 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 this database 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, and qualified support for the ‘strong’ version of the hypothesis. 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 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 OECD 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.

And finally, there is some indirect support for the ‘strong’ version of the hypothesis through 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”.

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