Environmental Policy, Innovation and Performance : New Insights on the Porter Hypothesis[1]

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Summary

In general, protection of the environment is perceived as an extra cost, or an extra burden for firms. However, during the last decade, this paradigm has been challenged by a number of analysts. In particular, Porter (Porter, 1991; Porter and van der Linde, 1995) has suggested that pollution is generally associated with a waste of resources, with raw material not fully used, 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 more stringent flexible environmental policies (economic instruments) would have positive economic (and not just environmental) consequences, stimulating innovations to eliminate these sources of waste and inefficiencies. These innovations may, in turn, compensate for the costs of complying with these policies. This is 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.

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 activities, 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 regimes give firms greater incentive to innovate than prescriptive regulations, such as technology-based standards. Finally, the "strong" version posits that more stringent environmental policy may induce innovation that may compensate (or more than compensate) for the cost of complying with it. Many researchers have tested different versions of the Porter Hypothesis empirically, but the results are mixed.

Given the growing importance of environmental issues in our society, the challenging and controversial nature of the Porter Hypothesis, and the mitigated nature of the empirical results obtained so 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 described above or, in other words, to test the three "versions" of PH. This database is the cornerstone for a research project launched by the OECD and entitled "Environmental policy and corporate behaviour". It includes observations from approximately 4200 facilities in seven OECD countries. Information is available on the 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, as well as a number of control variables. 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 policy, research and development, environmental performance and commercial performance). This allows us to obtain greater insight on the mechanisms at play, and on the empirical validity of the Porter Hypothesis. 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.

1. Introduction

Managers have long associated environmental protection with the imposition of additional costs by the government, which may erode firms'competitiveness. This view relies on the premise that markets work well to reach an optimal use of scarce resources, so that government intervention is only useful to redistribute revenues, or to correct market imperfections. This is precisely what occurs in the case of environmental problems. One of the prerequisites for the adequate functioning of markets is the existence of well-defined ownership rights. Evidently, in the case of environmental resources such as air or water, these rights are very difficult to assign. Therefore, because air and water belong to no one (or to anyone), economic agents may use them at zero cost, whereas the actual cost of this use for the society as a whole is certainly greater. Polluters receive the wrong signal and, because they use these resources without paying the true price, they are encouraged to do so to excess.

Left alone, the market generates too much pollution compared with the socially optimal level. Government intervention is required in order to reduce pollution to an optimal level. To this effect, the government has at its disposal a panoply of instruments such as direct regulation, environmental taxation or tradable pollution permits[2], which confront firms with the social cost of their production decisions. In short, from this perspective, consideration of the environment is associated with a cost increase for companies that have previously used environmental resources with impunity, since benefits which are external to firms are 'internalised' to them through policy intervention.

However, during the last decade, this paradigm has been challenged by a number of analysts. In particular, 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

[2] In general, it is considered that "market-based" instruments like green taxes and pollution permits should be preferred over regulation, because they provide incentives for abatement cost minimization and for continuous innovation.

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 more stringent flexible environmental policies (economic instruments) would have positive economic (and not just environmental) consequences, stimulating innovations to eliminate these sources of waste and inefficiencies[3]. These innovations may, in turn, compensate for the costs of complying with these policies. This is 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. This line of reasoning can be represented by the following diagram:

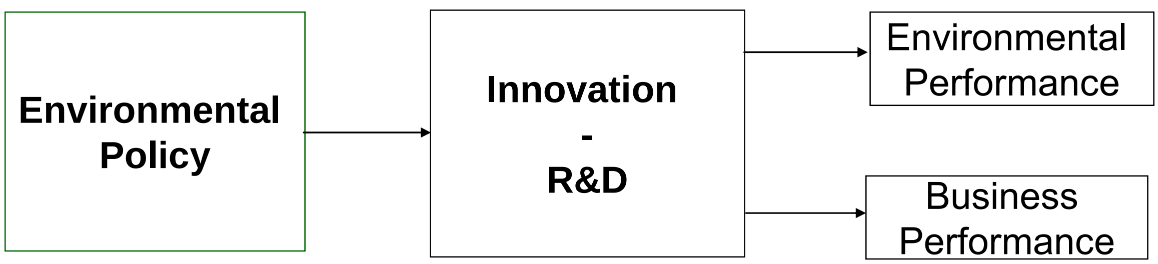


FIGURE 1

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 emissions and their costs. As such, it can hardly be generalized to the whole economy. 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).

[3] Porter specifically identifies two types of innovation that may enhance firms' performance: Process offsets and product offsets. Process offsets occur when environmental regulation not only leads to reduced pollution, but also results in higher resource productivity such as higher process yields, material savings, better utilization of by-products, etc. Product offsets occur when environmental regulation produces not just less pollution, but also creates better performing or higher–quality products, safer products, lower product costs, products with higher resale or scrap value, etc. (Porter and van der Linde, 1995).

Indeed, Ambec and Barla (2007) 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 specific investments with 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 regimes give firms greater incentive to innovate than prescriptive regulations, such as technology-based standards. Finally, the "strong" version posits that more stringent environmental policy may induce innovation that may compensate (or more than compensate) for the cost of complying with it.

Many researchers have tested different versions of the Porter Hypothesis empirically, and we can distinguish two sets of studies. In the first set, researchers examine whether more stringent environmental policies lead to greater innovation (the "weak" version). Results are ambiguous, they depend on the measure of the stringency of the environmental policy regime, and on the measure of environmental innovation (patents or R&D expenditures). No study has provided a comprehensive test of the "narrow" version. The second set of studies, which test whether more stringent environmental policies are beneficial to the firm (the "strong" version), has a long tradition in the economic literature (see Jaffe et al., 1995, for a review). In these studies, the impact of environmental regulation is estimated on measures of firms' performance, such as productivity and costs. The papers are in general silent on the process that leads to higher productivity. In general, the papers reviewed in Jaffe et al. (1995) highlight a negative impact of environmental regulation on productivity, but more recent papers (e.g., Berman and Bui, 2001, Alpay et al., 2002) find more positive results.

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 (described below) is the cornerstone for a research project launched by the OECD (www.oecd.org/env/cpe/firms). It includes observations from approximately 4200 facilities in seven OECD countries (USA, Canada, Japan, Germany, France, Hungary and Norway). Information is available on the 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, as well as a number of control variables[4]. 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 policy, technological innovation, environmental performance and commercial performance). This allows us to obtain greater insight on the mechanisms at play, and on the empirical validity of the Porter Hypothesis.

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

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

2. Literature survey

As mentioned in the introduction, we distinguish two set of 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 beneficial to the firm, i.e. the "strong" version. Yet these papers are silent on the process that leads to higher productivity. Table 1 in the appendix (adapted from Ambec and Barla, 2007) summarizes several empirical papers that belong to these two sets.

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. (2007) found a positive and significant relationship between environmental regulation stringency and the probability of running an environmental R&D program.

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 the U.S. electric utilities in the 1970s, with the age of capital assumed to be negatively related with environmental performance. According to Gray and Shabegian (1998), 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 the economic literature (see Jaffe et al., 1995, for a review). Most papers reviewed in Jaffe et al. (1995) highlight a negative impact of environmental regulation on productivity. For instance, Gallop and Robert (1983) estimated that SO_2 regulations slowed down productivity growth in the U.S. in the seventies by 43%. More recent papers (see Table 1) 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[5].

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 innovations. However, at least two studies provide indirect evidence supporting the narrow version. First, Burtraw (2000) provides results showing that the change in environmental regulation for SO_2 emissions in the U.S. from a technology-based standard

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

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 Btus 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 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 are incentives for further upgrading of scrubber efficiency[6].

In the same vein, Isaksson (2005) examined the impact of a charge on nitrogen oxides (NO_x) emissions introduced in Sweden in 1992. She examined the impact on abatement cost functions of 114 combustion plants during the period 1990 – 1996. Her findings suggest that extensive emission reductions have taken place at zero or very low cost, and that effects of learning and technological development in abatement have been present during the period analyzed.

Unlike the papers cited which use "traditional" productivity indexes that do not include pollution as an input or an output, Repetto et al. (1997) apply a "green" measure of productivity, which includes pollution as an undesirable output with a negative price, corresponding to the marginal damage of pollution (see Fare, et al., 1989). The measure of 'green' productivity would, of course, coincide with the conventional measure of productivity if the firms bore the full social cost of pollution through environmental

6 Lastly, the switch from technological standard to tradable emission allowances led to an organizational change. The responsibility for compliance that rested traditionally with engineers or chemists, typically in charge of environmental issues, has been transferred to top executives such as financial vice presidents, who are trained to treat SO_2 emissions allowance as financial assets. See Johnstone (2005) for a discussion and some evidence.

regulations in line with the polluter-pays-principle. However, with inadequately stringent regulations, or in an unregulated industry, the gap between the two measures can be substantial. Repetto et al. (1997) estimated an increase of productivity by 0.36 to 0.44 percent each year instead of 0.16 annually in the 1970s and 1980s for the electric power and pulp and paper industries, after including the cost of pollution in the productivity measure.

A number of papers have emerged from the OECD project, four of them being more closely related to our research agenda. First, Arimura et al. (2007) use a bivariate probit model to examine the link between the stringency of environmental policies and environmental R&D, in which the other 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. And finally, Johnstone et al. (2007b) examine the effect of different policy instruments on environmental performance with respect to wastewater, air pollution, and solid wastes generated by facilities, as well as the decision to invest in "concrete actions" in these three areas. They find that, once the effect of policy stringency is accounted for, the precise mix of instruments applied is not particularly important[7].

[7] Other papers, like Henriques et al. (2007), examine the determinants of the adoption of an environmental management system (EMS).

3. Empirical model, econometric strategy and data

A unique 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 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%.

Table 1: Response Rate by Country

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

While surveys undertaken as part of official data collection exercises may have higher response rates, in many such cases there are legal obligations to respond. Other studies also focus on large firms (e.g. Standard and Poor 500), or firms with other attributes (i.e.

listed on the stock exchange), which are likely to have higher response rates. Indeed, given the population sampled, the response rate was higher than had been anticipated.

Table 2 provides data on the number of respondent facilities by industrial sector for the seven countries. While the sectoral data is available at the ISIC two digit level (24 sectors), the data is presented in somewhat aggregated form below. 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).

Unfortunately, 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 can be found at (http://www.oecd.org/dataoecd/36/35/37265864.pdf). In addition, the reliability of the R&D expenditure data can be examined by comparing the Japanese sample in the OECD survey with data collected as part of the *Survey of Research and Development 2002*[8] which has been conducted in Japan for more than a decade. As in our study, respondents were requested to provide information on the specific purposes of the research expenditures, including environmental conservation. Among 4 312 facilities which replied to this question, 8.4% or 360 facilities had environment related research expenditure. In the OECD survey, the corresponding figure was 12%. 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 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[9] and compared 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

[8] 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.

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

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 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 $\lambda_i \sim N(0, 1)$[10].

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:

*How important do you consider each of the following potential **negative environmental impacts** from your facility's products and production processes? (Please tick one box for each row)*

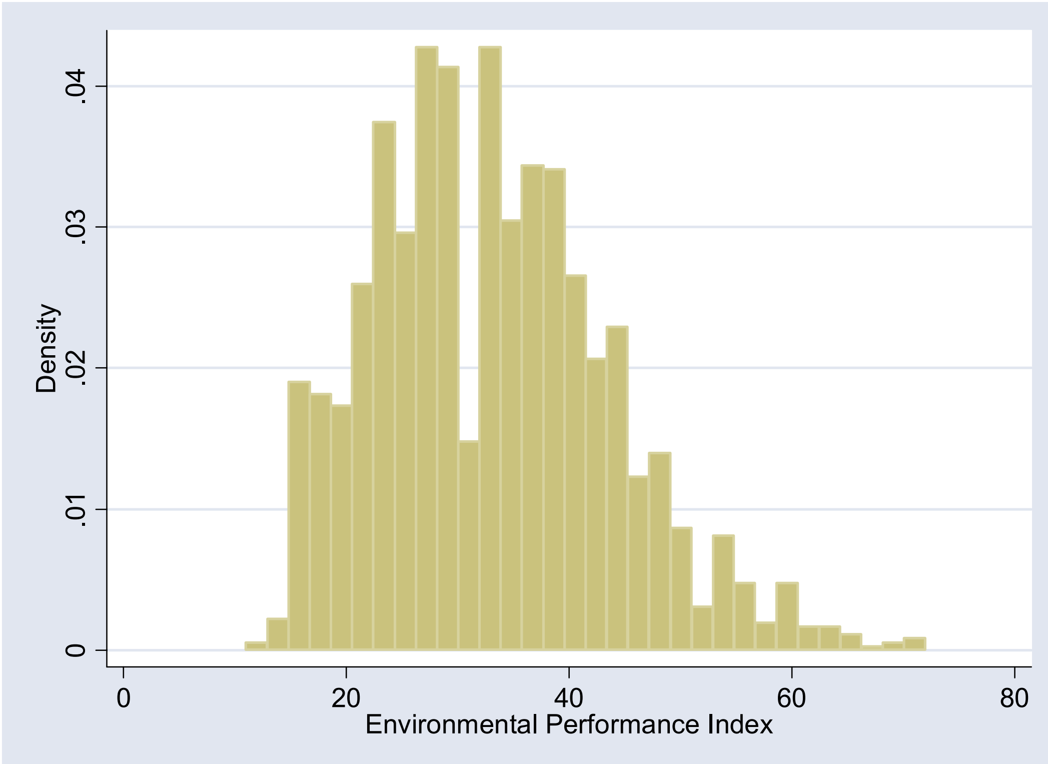
	No Negative Impact	Moderately Negative Impact	Very Negative Impact	Not Applic.
Use of natural resources (energy, water, etc.)				
Solid waste generation				
Wastewater effluent				
Local or regional air pollution				
Global pollutants (*e.g.* greenhouse gases)				
Aesthetic effects (noise, smell, landscape)				
Soil contamination				
Risk of severe accidents				
Other impact (please specify)______________				

*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? (Please tick one box for each row)*

10 : η_i and λ_i are, formally, the error terms of the model involving the unobserved latent variables

The same items as in the preceding question are presented to the respondents, who are requested to choose from amongst the following for each impact: "Significant Increase"; "Increase"; "No change"; "Decrease"; "Significant Decrease", plus "Not Applicable". Only the first five impact areas are retained for this study (i.e. use of natural resources, solid waste, wastewater, local and regional air pollutants, and global air pollutants), since they are the primary targets of environmental policy in the manufacturing sector. 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. Thus, a facility which reports that it has "significantly decreased" (5) an impact which it perceives as being potentially "very negative" (3) obtains a greater score (15), than a facility which reports that it has "significantly decreased" (5) an impact, which it perceives as only being "moderately negative" (2) for a score of 10. 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 from 15 to 75.



Previous authors who have used this database (Johnstone et al, 2007b, Darnall et al., 2007) have considered a binary variable taking the value 1 when a facility reports that it has “significantly decreased” or “decreased” 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? (Please tick only one box)*

Revenue has been so low as to produce large losses	1
Revenue has been insufficient to cover costs	2
Revenue has allowed us to break even	3
Revenue has been sufficient to make a small profit	4
Revenue has been well in excess of costs	5

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, given the overall structure of our model, when we estimate the ENVIRONMENTAL R&D equation, we use an instrument because we strongly suspect the presence of simultaneity between ENVIRONMENTAL R&D and BUSINESS PERF (as well as between ENVIRONMENTAL R&D and ENVIRONMENT PERF). The decision to undertake R&D investment 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. 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 undertake 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[11] 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). Furthermore, in this equation, FIT ENVIRONMENTAL R&D is the fitted value of the preceding equation.

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

In the BUSINESS PERF equation, the variable FIT ENVIRONMENTAL PERF is the fitted value of the preceding equation[12], and the variable FIT ENVIRONMENTAL R&D is also the fitted value of the ENVIRONMENTAL R&D equation.

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? (Please tick only one box)*

Not particularly stringent, obligations can be met with relative ease	1
Moderate stringency, require some managerial and technological responses	2
Very stringent, has a great deal of influence on decision-making in the facility	3

Given that it could be arbitrary to consider 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.

The following variables related to the environmental policy regime are obtained from the response to the following question:

[12] 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.

Please assess the following environmental policy instruments in terms of their impacts on your facility's production activities. (Please tick one box for each row)[13]

	Not Important 1	Moderately Important 2	Very Important 3	Moderately Important 4
Technology-based standards				
Performance-based standards				
Input taxes				
Emission or effluent taxes or charges				

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"[14]. 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).

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 simply not have the resources to invest in efficient research. 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

[13] 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.
[14] See previous footnote.

a review.) As in many other papers, we use these measures in log terms. Standard theory has ambiguous predictions concerning the impact of market concentration on innovation (CONCENTRATION1 and CONCENTRATION2)[15]. The Schumpeterian view predicts that facilities in more concentrated industries are more likely to undertake 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, market powered firms tend "to rest on their laurel" because the replacement effect (e.g., Tirole, 1989) leads to opposed predictions.

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 present in many markets 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 actions related to environmental matters. A specific budget attributed to environmental issues may be one way to do so. 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 want to signal their actions related to environmental issues. We also have three variables to capture the spatial scope of the market in which they

[15] 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.

operate (MARKETSCOPE1, MARKETSCOPE2, MARKETSCOPE3)[16]. 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 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.[17]

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

[16] 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.
[17] 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).

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.

Table 3: Descriptive statistics for the main variables

Variable	Description	Mean	Std. Dev.	Min	Max
Environmental R&D	Does facility have enviro R&D budget? (0=no; 1=yes)	.09296	0.2904	0	1
Environmental Perf.	Index of environmental performance (scale= 0 to 75)	33.02183	10.5622	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)	3.460294	.9894761	1	5
Stingency1	The environmental policy regime is not particularly stringent, obligations can be met with relative ease (0=no, 1=yes)	.3595318	.4799205	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)	.1593407	.3660372	0	1
Tech-standards1	The technology-based standards are not important (0=no, 1=yes)	.1571906	.3640239	0	1
Tech-standards2	The technology-based standards are moderately important (0=no, 1=yes)	.3547539	.4784959	0	1
Tech-standards3	The technology-based standards are very important (0=no, 1=yes)	.207119	.4052899	0	1
Perf-standards1	The performance-based standards are not important (0=no, 1=yes)	.1118012	.3151594	0	1
Perf-standards2	The performance-based standards are moderately important (0=no, 1=yes)	.3874821	.4872334	0	1
Perf-standards3	The performance-based standards are very important (0=no, 1=yes)	.3081701	.4617924	0	1
Tax1	The environmental taxes are not important (0=no, 1=yes)	.2326804	.4225907	0	1
Tax2	The environmental taxes are moderately important (0=no, 1=yes)	.4749164	.4994301	0	1
Tax3	The environmental taxes are very important (0=no, 1=yes)	.3110368	.4629731	0	1
USA	Dummy for the country (omitted = Canada)	.116818	.3212416	0	1
Germany	"	.2145246	.4105412	0	1
Hungary	"	.1113235	.3145698	0	1
Japan	"	.3580984	.4794986	0	1
France	"	.0642618	.2452481	0	1
Norway	"	.0738175	.2615049	0	1
Food	Dummy for the sector (omitted = recycling)	.1003344	.3004813	0	1
Leather	"	.0489728	.2158369	0	1
Wood	"	.050645	.2192979	0	1
Pulp	"	.0788342	.269512	0	1
Coke	"	.151935	.3590008	0	1
Nonmetal	"	.0355948	.1852999	0	1
Metal	"	.1975633	.3982084	0	1

Machinery	"	.237936	.4258706	0	1
Motor	"	.0692785	.2539576	0	1
Age	Age of the facility	36.13481	21.58165	0	99
Log (employment)	# of full time employees in facility (log)	5.106071	1.047386	.6931	10.2617
Log (employment)^2	Squared # of full time employees in facility (log)	27.16871	11.48056	.4804	105.3044
Concentration1	Number of competitors (less than 5 or not)	.2639752	.4408386	0	1
Concentration2	Number of competitors (between 5 and 10 or not)	.3440038	.4750991	0	1
Multi-facility	Does the facility belong to a multi-facility enterprise (0=no, 1=yes)	.5203058	.4996472	0	1
Firm intl	Head office located in foreign country? (0=no; 1=yes)	.1198746	.324854	0	1
Firm quoted	Listed on a stock exchange? (0=no; 1=yes)	.1674317	.373406	0	1
Primary cust	Primary customers of the facility's products (1="Households" or "Wholesalers or retailers", 0 otherwise)	.3731486	.4836989	0	1
Marketscope1	Scope of facility's market (local or not)	.4092212	.4917489	0	1
Marketscope2	Scope of facility's market (national or not)	.4092212	.4917489	0	1
Markescope3	Scope of facility's market (regional or not)	.1075012	.3097864	0	1
Instrument R&D	Instrument: Average percentage of facilities in the same sector and same country with a specific environmental R&D budget.	.0893454	.051144	0	.2608
Total R&D	Please estimate your facility's average annual expenditures on research and development over	2.22e+08	6.92e+09	0	3.60e+11
Environmental perf. (0,1)	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? (1="Decrease" or "Significant decrease", 0 otherwise)	.6932633	.4611942	0	1

5. Empirical results

Table 4 reports the estimated coefficients in our three main equations. Panel A is devoted to the Environmental R&D equation, Panel B to the Environmental Performance equation, and Panel C to 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 in a different way one of the three dependent variables. In column (2) of each panel, we repeat the same exercise, but using total R&D as a measure of innovation generated by more rigorous environmental regulation. 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). In this case, the Environmental R&D equation is not affected by this change in the measure of environmental performance. 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).

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

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 Environmental 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

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 $(\text{employment})^2$	.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	

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 comforting. 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" command-and-control instruments (performance standards) have more impact on environmental innovation than more prescriptive measures (technology-based standards), which is, in a sense, in line with Porter's narrow version.

Among the control variables, it is noteworthy that the 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 want 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.

Arimura et al. (2007) 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[18]. 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.

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

[18] 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. 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 the 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 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 have no 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 a 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[19]. 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). This suggests that, in spite of the finding that environmental regulation may induce beneficial innovations, its overall impact on business performance is negative. 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 somewhat 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 clean production is rather influenced by “cost savings”

[19] 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.

motivations[20]. No other environmental policy variable is significant, nor is the FIT ENVIRONMENTAL PERF variable.

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 other 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.

Let us discuss the results when we use alternative approaches (columns (2), (3) and (4)). When we use Total 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

[20] 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.

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 (recall that the coefficient of FIT ENVIRONMENTAL R&D was weakly significant in our preferred specification). 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 keeps 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 carrying the message 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, for the first time, 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. While some of these costs may be offset by the efficiency gains identified through investment in R&D, the net effect remains negative.

References

Alpay, E., S. Buccola and J. Kerkvliet (2002) 'Productivity Growth and Environmental Regulation in Mexican and U.S. Food Manufacturing', American Journal of Agricultural Economics 84(4):887-901.

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

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

Ambec, S. and P. Barla (2007) 'Can environmental regulations be good for business? An assessment of the Porter Hypothesis' working paper GREEN, Laval University, forthcoming in Energy Studies Review

Arimura, T., Hibiki, A., Johnstone, N. (2007) "An Empirical Study of Environmental R&D: What Encourages Facilities to be Environmentally-Innovative?" in Johnstone, N. (Ed.) Corporate Behaviour and Environmental Policy Cheltenham UK: Edward Elgar in association with OECD.

Arimura, T.H., A. Hibiki, S. Imai and M. Sugino (2005), "Empirical Analysis of the Impact that Environmental Policy has on Technological Innovation", Paper prepared for Final Meeting of Collaboration Projects 2004 "Sustainable Economic Growth and the Challenges of Global Warming" at The Economic and Social Research Institute, Cabinet Office, Government of Japan http://www.esri.go.jp/en/prj-2004_2005/kankyou/kankyou16/syousai-e.html

Barbera, A.J. and V.D. McConnell (1990) 'The Impact of Environmental Regulations on Industry Productivity: Direct and Indirect Effects', Journal of Environmental Economics and Management 18, 50-65.

Berman, E. and L.T.M. Bui (2001) 'Environmental regulation and productivity: evidence from oil refineries' The Review of Economics and Statistics 83(3): 498-510.

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

Burtraw, D. (2000) "Innovation Under the Tradable Sulfur Dioxide Emission Permits Program in the U.S. Electricity Sector", Discussion Paper 00-38, Resources For the Future (RFF), Washington.

Cordeiro, J., Sarkis, J. (1997) "Environmental Proactivism and Firm Performance: Evidence from Security Analyst Earnings Forecasts" Business Strategy and the Environment 6, 104-114.

Darnall, N. G.; Jolley, J.; Ytterhus, B. (2007) "Understanding the Relationship between a Facility's Environmental and Financial Performance" in Johnstone, N. (Ed.) Corporate Behaviour and Environmental Policy Cheltenham UK: Edward Elgar in association with OECD.

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

Dufour, C., P. Lanoie and M. Patry (1998) 'Regulation and Productivity', Journal of Productivity Analysis 9, 233-247.

Fare R., S. Grosskopf, C.A.K. Lovell and C. Pasurka (1989), 'Multilateral Productivity Comparison when Some Outputs are Undesirable: a Nonparametric Approach', Review of Economics and Statistics, 71, 90-98.

Frondel, M.; Horbach, J.; Rennings, K. (2007) "End-of-Pipe or Cleaner Production? An empirical Comparison of Environmental Innovation Decisions Across OECD Countries" in Johnstone, N. (Ed.) Corporate Behaviour and Environmental Policy Cheltenham UK: Edward Elgar in association with OECD.

Gabel, H.L. and B. Sinclair-Desgagné (2002), 'The Firm, its Procedures, and Win-Win Environmental Regulations' in Henk Folmer et al. Frontiers of Environmental Economics (Cheltenham, UK).

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

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

Gray, W.B., (1987) 'The Cost of Regulation: OSHA, EPA and the Productivity Slowdown', American Economic Review 77(5):998-1006.

Gray,W.; Deily, M.E. (1996) "Compliance or Enforcement: Air Pollution Regulation in the U.S. Steel Industry" Journal of Environmental Economics and Management 31, 96-111.

Greaker, M. (2003), 'Strategic Environmental Policy; Eco-dumping or a Green Strategy?', Journal of Environmental Economics and Management 45, 692-707.

Hart, S.L. and Ahuja, G. (1996) « Does it Pay to be Green? An Empirical Examination of the Relationship between Emission reduction and Firm Performance" Business Strategy and the Environment 5, 30-37.

Hausman, J., (1996) "Valuation of New Goods under Perfect and Imperfect Competition," in T. Bresnahan and R. Gordon, eds., The Economics of New Goods, Studies in Income and Wealth, Vol. 58, Chicago: National Bureau of Economic Research.

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

Henriques, I., Sadorsky, P., Kerekes, S. (2007) “Environmental Management Systems and Practices: An International Perspective” in Johnstone, N. (Ed.) Corporate Behaviour and Environmental Policy Cheltenham UK: Edward Elgar in association with OECD.

Hoglund Isaksson, L. (2005) “Abatement Costs in Response to the Swedish Charge on Nitrogen Oxide Emissions” Journal of Environmental Economics and Management 50, 102-120.

Jaffe, A. B.; Peterson, S. R.; Portney, P. R.; Stavins, R. N. (1995) « Environmental Regulation and International Competitiveness : What Does the Evidence Tell Us ? » Journal of Economic Literature 93, 12,658-12,663.

Jaffe, A.B.; Palmer, K. (1997) “Environmental Regulation and Innovation: A Panel Data Study” Review of Economics and Statistics 79(4): 610-619.

Jaumotte, F. and Pain, N. (2005) ‘From Ideas to Development: The Determinants of R&D and Patenting’ OECD Economics Department Working Paper No. 457 - ECO/WKP(2005)44 .

Johnstone, N. (2005) ‘Tradeable Permits: Implications for Monitoring and Enforcement’ in D. Helm (ed.) *Climate Change Policy* (Oxford: Oxford University Press)

Johnstone, N. and J. Labonne (2006) ‘Environmental Policy, Management and Research and Development' in OECD Economic Studies, Vol. 46.

Johnstone, N., Serravalle, C.; Scapecchi, P.; Labonne, J. (2007a) “Public Environmental Policy and Corporate Behaviour: Project Background, Overview of the Data and Summary Results” in Johnstone, N. (Ed.) Corporate Behaviour and Environmental Policy Cheltenham UK: Edward Elgar in association with OECD.

Johnstone, N.; Glachant, M.; Serravalle, C.; Riedinger, N.; Scapecchi, P. (2007b) “Many a Slip Twixt the Cup and Lip: Direct and Indirect Policy Incentives to Improve Corporate environmental Performance” in Johnstone, N. (Ed.) Corporate Behaviour and Environmental Policy Cheltenham UK: Edward Elgar in association with OECD.

King, A., Lenox, M. (2001) “Does it Really Pay to be Green? Accounting for Strategy Selection in the Relationship between Environmental and Financial Performance” Journal of Industrial Ecology 4, 105-116.

Konar, S., Cohen, M.A. (2001) “Does the Market Value Environmental Performance?” Review of Economics and Statistics 83, 281-289.

Lanoie, P.; Laplante, B.; Foulon, J. (2002) «Incentives for Pollution Control : Regulation or Information?» Journal of Environmental Economics and Management vol. 44, 169-187.

Lanoie, P.; Patry, M.; Lajeunesse, R. (2005) « Environmental Regulation and Productivity : New findings on the Porter Hypothesis », mimeo, HEC Montréal.

Lanoie, P.; Tanguay, G. (2000) «Factors Leading to Green Profitability : Ten Case Studies» Greener Management International, 31, 39-50.

Lanoie, P.; Tanguay, G. (2004) «Dix exemples de rentabilité verte» Risque et management international 3, 85-106.

Lanoie,P.; Thomas, M.; Fearnley, J. (1998) «Firm Responses to Effluent Regulations : Pulp and Paper in Ontario, 1985-1989» Journal of Regulatory Economics 13 (1998) : 103-120.

Mohr R.-D. (2002), "Technical Change, External Economies, and the Porter Hypothesis", Journal of Environmental Economics and Management 43(1), 158-168.

Nelson R.A., T. Tietenberg and M.R. Donihue (1993) 'Differential Environmental Regulation: Effects on electric utility capital turnover and emissions' The Review of Economics and Statistics 75(2): 368-373.

Nevo A. (2000a) "Measuring Market Power in the Ready-to-Eat Cereal Industry," Econometrica, 69, 307-342

Nevo A. (2000b) "Mergers with Differentiated Products: The Case of the Ready-to-Eat Cereal Industry," Rand Journal Economics, 31, 395-421.

Oates, E.; Palmer, K.; Portney, P. R. (1995) « Tightening Environmental Standards : TheBenefit-Cost or the No-Cost Paradigm ? », Journal of Economic Perspectives, Vol. 9, no 4, 119-112.

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

Popp, D. (2006) "International Innovation and Diffusion of Air Pollution Control Technologies: The Effects of NOX and SO2 Regulation in the US, Japan, and Germany", Journal of Environmental Economics and Management, 51(1), 46-71.

Porter, M. (1991) "American Green Strategy" Scientific American 264, 168.

Porter, M., van der Linde, C. (1995) "Towards a New Conception of Environment-Competitiveness Relationship" Journal of Economic Perspective 9, 97-118.

Reinhardt, F.L. (2000) Down to Earth: Applying Business Principles to Environmental Management Boston: Harvard Business School Press

Repetto, Roberts, Dale Rothman, Paul Faeth et Duncan Austin (1996), Has Environmental Protection Really Reduced Productivity Growth?, World Resources Institute.

Russo, M.V., Fouts, P.A. (1997) "A Resource-Based Perspective on Corporate Environmental Performance and Profitability" Academy of Management Journal 40, 534-559.

Simpson David and Robert L. Bradford (1996), 'Taxing Variable Cost: Environmental Regulation as Industrial Policy', Journal of Environmental Economics and Management 30(3), 282-300.

Smith J.B. and W.A. Sims (1985), 'The Impact of Pollution Charges on Productivity Growth in Canadian Brewing', The Rand Journal of Economics 16(3): 410-423.

Tietenberg, T. (2007) Environmental Economics and Policy Addison-Wesley

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

Appendices

TABLE A1
Empirical studies on the Porter Hypothesis

STUDY	DATA	METHODOLOGY	MAIN RESULTS
I. Impact of Environmental Regulations (ERs) on Innovation and Technology			
Jaffe and Palmer (1997)	▪ Panel of U.S. manufacturing industries – 1973-1991.	▪ Reduced form model. ▪ Innovation proxy: R&D investments and number of successful patent applications. ▪ ERs proxy: Pollution control capital costs.	▪ R&D significantly increases with ERs. Elasticity: +0.15. ▪ No significant impact of ERs on number of patents.
Brunnermeier and Cohen (2003)	▪ Panel of 146 U.S. manufacturing industries 1983-1992.	▪ Reduced form model. ▪ Innovation proxy: number of environmentally-related successful patent applications. ▪ ERs: Pollution control operating costs and number of air and water pollution control inspections.	▪ Small but significant impact of pollution operating cost on number of patents. ▪ No impact of inspections.
Nelson et al. (1993)	▪ 44 U.S. electric utilities over the 1969-1983 period.	▪ Three-equation model: i) age of capital; ii) emissions; and iii) regulatory expenditures. ▪ Model includes two ER proxies: air pollution cost and total pollution control costs per KW capacity.	▪ ERs significantly increase age of capital (elasticity: +0.15). ▪ Age of capital has no statistically-significant impact on emissions. ▪ Regulation has impacted emission levels.
Arimura et al. (2007)	▪ Survey of 4 000 manufacturing facilities in seven OECD countries.	▪ Bivariate probit model with (1) Environmental R&D dummy regressed on various measures of environmental policy (perceived stringency, standards, taxes), an environmental accounting dummy and other management practices control variables. (2) Environmental accounting dummy regressed on same variables.	▪ The perceived ER stringency has a positive and significant impact on the probability to a run an environmental R&D program. ▪ The type of ER (standard or tax) has no significant effects on environmental R&D.
Popp (2003)	▪ Patent data and performance measures of flue gaz desulfurization units (“scrubbers”) of 186 plants	▪ SO2 removal efficiency of new scrubbers regressed on the flow of knowledge (measured by patents) and policy variables. ▪ Operating and maintenance cost of scrubbers regressed on same variables.	▪ The new SO2 emission permit regulation introduced in 1990 increased SO2 removal efficiency and lowered operating and removal costs.

Study	Data	Methodology	Main Results
	in US (1972-1997).		
Popp (2006)	▪ Patent data from the U.S., Japan, and Germany (1967-2001).	▪ Impact of SO_2 (US) and NO_X (Germany and Japan) ERs on patenting and patent citations. ▪ ERs: timing of the introduction of new ERs. ▪ Estimate the cross-countries spillovers using patent citation origins.	▪ ERs regulation followed by an increase of patenting from domestic firms but not from foreign firms. ▪ Earlier ERs for NO_X in Germany and Japan are important components of US patents for pollution control technologies to reduce NO_x emissions.
II. Impact of ERs on Productivity			
Gollop and Robert (1983)	▪ 56 U.S. electric utilities, 1973-1979.	▪ Productivity measure: derived from the estimation of a cost function that includes the ERs proxy. ▪ ERs: the intensity of SO_2 regulations based on actual emissions, state standard and the utility estimated unconstrained emission levels.	▪ ERs reduce productivity growth by 43%.
Smith and Sims (1983)	▪ 4 Canadian beer breweries, 1971-1980.	▪ Productivity measure: derived from the estimation of a cost function. ▪ Two breweries were submitted to an effluent surcharge and two breweries were not.	▪ Average productivity growth regulated breweries -0.08% compared to +1.6% for the unregulated plants.
Gray (1987)	▪ 450 U.S. manufacturing industries, 1958-1978.	▪ Change in average annual total factor productivity growth between 1959-69 period and the 1973-78 period regresses on pollution control operating costs.	▪ 30% of the decline in productivity growth in the seventies due to ERs.
Barbera and Mc Connel (1990)	▪ 5 U.S. pollution intensive industries (paper, chemical, stone-clay-glass, iron-steel, non-ferrous metals), 1960-1980.	▪ Derive the direct (abatement cost growth) and indirect (changes in other inputs and production process) effects of pollution control capital using a cost function approach.	▪ Overall, abatement capital requirements reduce productivity growth by 10% to 30%. ▪ Indirect effect sometimes positive.
Dufour, Lanoie and Patry (1998)	▪ 19 Quebec manufacturing industries, 1985-1988.	▪ Total factor productivity growth regressed on changes in the ratio of the value of investment in pollution-control equipment to total cost.	▪ ERs have a significantly negative impact on productivity growth rate.
Berman	▪ US petroleum	▪ Comparison of total factor	▪ Stricter regulations imply

STUDY	DATA	METHODOLOGY	MAIN RESULTS
and Bui (2001)	refining industry, 1987-1995.	productivity of California South Coast refineries (submitted to stricter air pollution regulations) with other US refineries. ▪ ERs severity is measured by the number of environmental regulations each refinery is submitted to.	higher abatement costs. However, these investments appear to increase productivity.
Lanoie, Lajeunesse and Patry (2005)	▪ 17 Quebec manufacturing industries, 1985-1994.	▪ Total factor productivity growth regressed on lagged changes in the ratio of the value of investment in pollution-control equipment to total cost.	▪ ERs have a significantly positive impact on productivity growth rate, especially in the sectors highly exposed to outside competition.
Alpay, Buccola and Kerkvliet (2002)	▪ Mexican and U.S. processed food sectors (1962-1994).	▪ Productivity measure obtained through the estimation of a profit function that includes pollution abatement expenditures (US) and inspection frequency (Mexico) as proxies for ERs.	▪ US: negligible effect of ERs on both profit and productivity. ▪ Mexico: ERs have a negative impact on profits but a positive impact on productivity.
Gray and Shadbegian (2003)	▪ 116 U.S. paper mills, 1979-1990.	▪ Regression of total factor productivity on pollution abatement operating costs, technology and vintage dummies and interaction terms between the dummies and the abatement variable. ▪ Estimation of a production function that includes beside input prices, pollution abatement costs and other control variables.	▪ Significant reduction in productivity associated with abatement efforts particularly in integrated paper mills.