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End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries

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Non-technical Summary

Typically, we distinguish between two different types of environmental innovations that mitigate the environmental burden of production: cleaner production and end-of-pipe technologies. Cleaner production reduces resource use and/or pollution at the source by using cleaner products and production methods, whereas end-of-pipe technologies curb pollution emissions by implementing add-on measures. Thus, cleaner products and production technologies are frequently seen as being superior to end-of-pipe technologies for both environmental and economic reasons.

The establishment of cleaner production technologies, however, is often hampered by barriers such as additional co-ordination input and a lack of organizational support within firms. In addition to substantial investment costs in new technologies, additional obstacles arise due to the nature of the environmental problem and the type of regulations involved. Command and Control (CaC) regulations, for instance, frequently impose technology standards that can only be met through end-of-pipe abatement measures. With particular respect to the diffusion of cleaner production and products, the question arises which one of several alternative policy approaches is to be preferred: performance standards, voluntary measures, or economic instruments which leave decisions about the appropriate abatement technology up to the firm?

This paper analyzes factors that may enhance a firm's propensity to implement cleaner products and production technologies rather than end-of-pipe technologies. It is a widespread assumption that end-of-pipe technologies still dominate investment decisions in firms. This is because there has been exceptionally little empirical analysis directed to the determinants of the use of specific types of abatement measures - principally because of the paucity of available data. On the basis of a unique facility-level data set based on a recent survey covering seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway, and the U.S.) we find a clear dominance of cleaner production in these countries: Surprisingly, 76.8% of our sample facilities report that they predominantly invest in cleaner production technologies. There are, however, significant differences: Most notably, Germany displays the lowest percentage of cleaner production technologies among these OECD countries (57.5 %), while Japan exhibits the highest respective share (86.5 %). The explanation is that Germany's command and control policy heavily supported end-of-pipe technologies in the past. Recent empirical results, however, point to a growing importance of cleaner technologies in Germany.

Our estimation results, which are based on multinomial logit models, indicate that cost savings tend to favor clean production and that regulatory measures and the stringency of environmental policy are positively correlated to end-of-pipe technologies. These results suggest that the application of end-of-pipe measures depends at least partially on regulatory pressure, whereas cleaner production may be motivated – among other factors – by market forces. Furthermore, we find empirical evidence that organizational innovations improve the technological capabilities of facilities: General management systems and specific environmental management tools such as process control systems or environmental audits seem to support the implementation of cleaner production measures, presumably by improving the necessary information basis for the development of such technologies. We thus conclude that improvements towards cleaner products and production may be achieved by developing and disseminating these management tools to a larger extent. Furthermore, the introduction of cleaner technologies and products is supported by R&D investment specifically related to environmental matters.

With particular respect to environmental product innovations, we find that a large majority of facilities in these OECD countries report that their measures are aimed at production processes and not so much at products to reduce environmental impacts. While pollution problems have been mastered quite successfully through the use of cleaner processes at the production site, product-integrated environmental innovations still seem to suffer from poor market incentives. Our estimation results based on a binary probit model indicate that the determinants of environmental product innovations are quite similar to those of process innovations. This might be explained by the fact that product-integrated environmental innovations include process changes "from cradle to grave", in other words, there is a wide overlap between these two types of innovations.

We conclude that additional investments in cleaner production and products may be stimulated by widening the cost gap between the two types of technologies, for instance, by additionally charging for the use of waste and energy. The potential for continuously substituting end-of-pipe technologies with cleaner technologies might be limited, however, since not all regulations favoring end-of-pipe technologies can be cut down. For example, additional filters currently reduce particulate emissions of Diesel cars more effectively than the more eco-efficient Diesel engines. Thus, a certain amount of end-of-pipe technologies will still be necessary to curb specific emissions which cannot easily reduced with cleaner production measures.

End-of-Pipe or Cleaner Production?
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Abstract. While both fundamental types of abatement measures mitigate the adverse environmental impacts of production, cleaner production technologies are frequently more advantageous than end-of-pipe technologies for environmental and economic reasons. This paper analyzes a variety of factors that might enhance firms' propensity to implement cleaner products and production technologies instead of end-of-pipe technologies. On the basis of a unique facility-level data set derived from a recent OECD survey, we find a clear dominance of cleaner production in seven OECD countries: Surprisingly, 76.8% of the facilities report that they invest predominantly in cleaner production technologies. With regard to environmental product innovations, the large majority of facilities reports that the measures they have undertaken to reduce environmental impacts were geared at production processes and not so much at products. Our estimation results are based on multinomial logit models which indicate that regulatory measures and the stringency of environmental policies are positively correlated with end-of-pipe technologies, while cost savings, general management systems, and specific environmental management tools tend to favor clean production. We conclude that improvements towards cleaner products and production may be reached by the continuous development and wider diffusion of these management tools. Improvements may also be stimulated by widening the cost gap between the two types of technologies, for instance, by additionally charging for waste and energy use.

Keywords: Cleaner production, end-of-pipe-technologies, technological innovation, technological change, government policy, discrete choice models.

JEL-Classification: Q55, O33, O38, C25

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1 Introduction

Typically, we distinguish between two different types of environmental innovations that mitigate the environmental burden of production: cleaner production and end-of-pipe technologies. Cleaner production reduces resource use and/or pollution at the source by using cleaner products and production methods, whereas end-of-pipe technologies curb pollution emissions by implementing add-on measures. Thus, cleaner products and production technologies are frequently seen as being superior to end-of-pipe technologies for both environmental and economic reasons.

The establishment of cleaner production technologies, however, is often hampered by barriers such as additional co-ordination input and a lack of organizational support within firms. In addition to substantial investment costs in new technologies, additional obstacles arise due to the nature of the environmental problem and the type of regulations involved. Command and Control (CaC) regulations, for instance, frequently impose technology standards that can only be met through end-of-pipe abatement measures. With particular respect to the diffusion of cleaner production and products, the question arises which one of several alternative policy approaches is to be preferred: performance standards, voluntary measures, or economic instruments which leave decisions about the appropriate abatement technology up to the firm?

There has been exceptionally little empirical analysis directed at the diffusion of specific types of environmental technologies, principally because of the paucity of available data (BRUNNERMEIER and COHEN, 2003; JAFFE et al., 2002). In particular, it is still unknown to what extent and why firms may shift from end-of-pipe solutions to cleaner production and products. There is a further set of related questions: First, do internal factors, such as the existence of environmental management systems (EMSs), support the environmental innovation decision for cleaner production and products? Secondly: Are innovation decisions driven by external factors, such as environmental regulations and pressure from suppliers, customers, or other stakeholders? Finally, do other factors than market demand for environmentally beneficial products also influence decisions in favor of environmental product innovations?

This paper empirically analyzes facilities' discrete choice between different environmental innovation types. On the basis of a facility and firm-level database derived from a recent OECD survey, we first attempt to identify the determinants of end-of-pipe and cleaner production technologies by using a multinomial logit model. We then employ a binary probit model in order to investigate the impact of these factors on the environmental product and process innovations selected by a facility. Our unique cross-country database allows us to address the influence of a variety of correlates, such as environmental policy instruments, market forces, the impact of pressure groups and (environmental) management tools on the firms' environmental innovation behavior.

Given the potential relative advantages of cleaner products and production technologies, it seems natural that policy makers are primarily interested in such incentives that affect the firms' choice among various types of environmental innovations. Furthermore, it appears particularly desirable from the perspective of environmental policy to identify incentives that can be influenced by policy measures, such as performance standards, flexible economic instruments, public procurement, voluntary measures, technology support programs, and to isolate motives that are mainly spurred by other determinants, such as consumer preferences and firm-specific factors.

In the subsequent section, we commence with the description of environmental innovation types and how these types are addressed in our analysis. Section 3 reviews the literature on trends and determinants pertaining to the shift from end-of-pipe to cleaner production. Section 4 provides a descriptive summary of our data set. In Section 5, we analyze the decision between end-of-pipe and cleaner production technologies using a multinomial discrete choice model. Section 6 uses the same variables to investigate whether determinants regarding the introduction of cleaner processes and products differ from each other. The final section concludes this study.

2 Types of Environmental Innovations

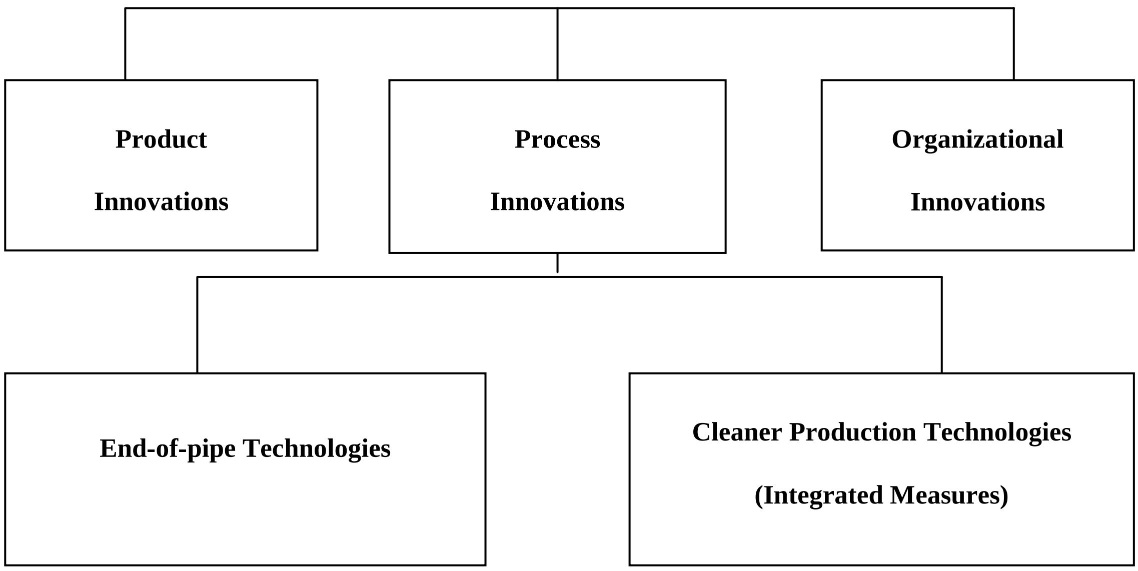
The OECD (1997) Guidelines for Collecting and Interpreting Technological Innovation Data distinguish between technical and organizational innovations, with technical innovations being divided into product and process innovations (for an illustration of theses distinctions, see Figure 1):

- Process innovations enable the production of a given amount of output (goods, services) with less input.
- Product innovations encompass the improvement of goods and services or the development of new goods.
- Organizational innovations include new forms of management, such as total quality management.

This distinction is in line with the technical guidelines of the Society of German Engineers (VDI) which sets forth industrial environmental protection measures and their respective costs (VDI, 2001). Process-related measures are commonly subdivided into end-of-pipe technologies and integrated technologies (hereinafter: cleaner production technologies). According to the VDI (2001) end-of-pipe technologies do not make up an essential part of the production process, but are add-on measures so as to comply with environmental requirements. Incineration plants (waste disposal), waste water treatment plants (water protection), sound absorbers (noise abatement), and exhaust-gas cleaning equipment (air quality control) are typical examples of end-of-pipe technologies. In contrast, cleaner production technologies are seen as directly reducing environmentally harmful impacts during the production process. The recirculation of materials, the use of environmentally friendly materials (e.g. replacing organic solvents by water), and the modification of the combustion chamber design (process-integrated systems) are examples of cleaner production technologies.

Typically, end-of-pipe technologies, such as filters utilized for desulphurization, aim at diminishing harmful substances that occur as by-products of production. In contrast, cleaner production measures generally lead to both reductions of by-products and energy and resource inputs. Finally, organizational measures include the re-organization of processes and responsibilities within the firm with the objective to reduce environmental impacts. Environmental management systems (EMS) are typical examples of organizational measures. Organizational innovations contribute to the firms' technological opportunities and can be supporting factors for technological innovations.

Figure 1: Types of Environmental Innovations



Frequently, firms hope that innovations will offset the burden and cost induced by environmental regulation or, at least, that they will help them to reach environmental policy goals without severe negative economic consequences. Reduced costs, increased competitiveness, the creation of new markets for environmentally desirable products and processes, positive employment effects, etc. are seen as potential benefits of an innovation-friendly environmental policy. Yet, these benefits can be realized more easily with cleaner products and cleaner production technologies than with end-of-pipe measures, since end-of-pipe technologies fulfill, by definition, primarily environmental protection tasks.

Thus, cleaner production technologies are frequently more advantageous than end-of-pipe technologies for both environmental and economic reasons. But technology choices are often influenced by the specific environmental problem and the regulatory framework stipulating a certain technology standard that can only be reached with end-of-pipe measures. Apart from the flexibility of regulation, the choice among these two technology options also hinges on the option that is more cost-effective when meeting the required standards.

In short, the total replacement of end-of-pipe technologies by cleaner production measures is certainly not possible. In practise, there will always be a mix of end-of-pipe and cleaner production technologies that depends on the underlying environmental targets, technology options, and related costs. Nevertheless, there is wide agreement on the following three findings. Firstly, environmental regulations relied far more on end-of-pipe in the past than on cleaner production technologies. Secondly, these technologies are still dominating in OECD countries, and, thirdly, shifts to cleaner production would be beneficial (RENNINGS et al., 2004a; 2004b).

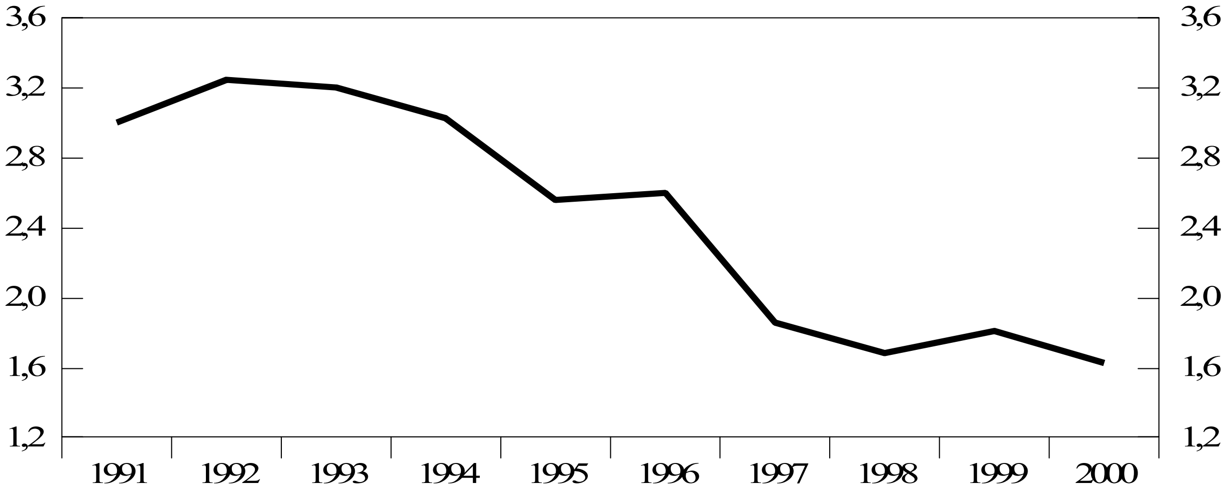
3 Trends and Determinants of Facilities' Environmental Technology Choice

Investments in cleaner production technologies cannot be separated all that easily from other, non-environmental technologies (SPRENGER, 2004). Therefore, data on the use of cleaner production technologies have hardly ever, if at all, been included in official environmental statistics thus far. Although international statistical offices, such as the OECD and, EUROSTAT (1999), agreed to add cleaner production to environmental protection activities, international statistics on the use of cleaner production technologies are still unavailable. On the other hand, statistical data indicates that investments in end-of-pipe technologies decreased during the 1990ies (for Germany, see Figure 2). This observation raises the question as to whether this fact might be explained by the shift of investments to cleaner production technologies.

Unfortunately, the literature on environmental innovation cannot provide a satisfying answer to this question to date, because it heavily draws upon insights of general empirical innovation research, which neither distinguishes between environmental and non-environmental innovations nor between end-of-pipe and cleaner production technologies. In the remaining part of this section, we will review the innovation literature with a focus on the general determinants of innovation decisions that may be decisive for the choice of environmental abatement technologies.

Figure 2: Investments in End-of-pipe Technologies in German Industry in the 1990ies (BECKER and GRUNDMANN (2002:421-422)).

In Billion Euros



The general innovation literature discussed intensely as to whether technological innovation is triggered by supply-push or demand-pull factors, or by both. Often, these factors are also called technology-push and market-pull factors, respectively, with market-pull factors emphasizing the role of consumers', firms' and the government's demand as determinants of environmental innovation (HEMMELSKAMP, 1997). While corporate image and preferences for environmentally friendly products are typical examples of market-pull factors, technology-push factors include subsidies that promote research and development (R&D).

Empirical evidence indicates that both market-pull and technology-push factors are relevant for spurring technological progress and innovation (PAVITT, 1984). This also seems to be plausible for the choice among environmental abatement technologies, with market-pull factors being expected to be more important for cleaner products and processes than for end-of-pipe technologies. The major technology-push and market-pull factors found in innovation literature are the technological capabilities, the possibility of appropriation, market structure and other factors that are described in the following section.

Technological capabilities

The concept of technological capabilities, conceived by ROSENBERG (1974), encompasses the knowledge and know-how of the development of new processes and products. Empirical studies support the hypothesis that technological capabilities are decisive determinants of innovation cost. They are thus important factors for innovation decisions (COHEN, 1995) and relevant for both cleaner production and end-of-pipe technologies. JANZ et al. (2003) find evidence that private R&D activities are decisive internal push factors for innovation activities, especially for knowledge-intensive sectors. Financial resources and skilled employees (CZARNITZKI, 2002), R&D activities, especially activities dedicated to environmental issues, and the support of organizational structures, such as management systems, in particular EMSs also represent important internal capabilities for successful innovation activities. Empirical evidence on the positive impact of EMSs on environmental innovation is found by RENNINGS et al. (2003) and REHFELD et al. (2004), while FRONDEL et al. (2004a) do not find any significant influence.

Possibility of appropriation

Research investment differs from physical investment, because it is difficult to exclude third parties from the assets produced by the research process. As noted in the classic contribution by ARROW (1962), the creator of these assets will typically fail to appropriate most or even all of the social returns it generates. Much of the social returns will accrue as spillovers to competing firms and consumers. The appropriation problem is likely to lead to significant underinvestment in R&D by private firms (JAFFE et al., 2002). Innovation incentives may increase if the private innovator can appropriate the expected innovation rents. The creation of a temporary monopoly by patents, the implementation of market barriers to complicate and hamper imitation, or keeping the innovation secret are instruments that can be used to ensure appropriation. Yet, the appropriation problem seems to be of minor importance for environmental innovations, since the expected rents are rather low due to the good public character of most environmental goods and services. In addition, this problem can be expected to be of lower importance for environmental process innovations than for product innovations.

Market structure

One of two major innovation incentives is the expectation of innovation rents, even if these rents are temporary (COHEN, 1995). In addition to R&D investment profits, strategic advantages over rivals are also motivating forces for innovations (CARRARO 2000). Innovation rents are commonly expected to be higher in oligopolistic regimes than in highly competitive markets. SCHUMPETER (1942) argues that firms with large market shares are superior with regard to innovations due to potential economies of scale for inventive activities. There is also empirical evidence that highly concentrated industries are more innovative than others (MANSFIELD, 1968, SCHERER, 1967). Yet, once monopolistic rents are secured, the pressure to innovate may decrease. New products and processes are more frequently developed in deregulated markets than in regulated markets (BEISE and RENNINGS, 2003). Thus, a few empirical studies also find support for the hypothesis that market concentration has a negative effect on innovations (GEROSKI, 1990, WILLIAMSON, 1965). Regarding the technology choice between end-of-pipe and cleaner production, it can be expected that firms in protected markets are more likely to opt for end-of-pipe technologies. They can concentrate on environmental protection functions since they experience less competitive pressure to simultaneously improve their resource efficiency.

Miscellaneous factors, such as market demand, sector specific differences, and firm size

Both actual and expected market demand crucially affect firms' decisions on R&D investments, especially concerning product innovations (HARABI, 1997). Of course, this also holds true for cleaner production investments and, in particular, environmental product innovations. Furthermore, due to specific market situations and technology options the "modes of innovative search" and the technology choice between end-of-pipe and cleaner production measures differ from sector to sector (DOSI, 1988). Innovation processes in the pharmaceutical industry, for example, appear to be rather complex, particularly in comparison to the textile industry, where innovations frequently consist in changes of textile designs. Finally, the complexity of innovations seems to determine the role that the firm's size plays for innovation behavior. Empirical findings are controversial, though. While complex innovations - most notably process innovations - can be easily accomplished by large firms, less complex innovations - commonly product innovations - frequently originate from small firms due to their higher degree of flexibility (PAVITT, 1984). The general existence of economies of scale for innovation activities has not yet been empirically confirmed.

Beyond such technology-push and market-pull factors, regulations are often considered to be an important driving force for environmental innovation. This is at least partially due to the public-goods character of environmental innovation (RENNINGS, 2000) which leads to underinvestment in environmentally related R&D. It is argued that market forces alone would provide insufficient innovation incentives and that consumers' willingness to pay for environmental improvements would be too low. The Porter Hypothesis underscores the view that regulations can trigger environmental innovations and postulates that in a non-optimizing world strict environmental policy may spur "innovation offsets", that is, environmental innovations can offset the burden and cost induced by regulations and create new markets for environmentally desirable products and processes. In a series of case studies, PORTER and VAN DER LINDE (1995) find anecdotical evidence for their hypothesis.

The Porter Hypothesis has been received with skepticism, however (see JAFFE and PALMER (1996)). While it is widely agreed that potentials for cost savings and improved efficiency may exist in imperfect markets, it is frequently argued that these potentials are rather limited (ULPH, 1996). Nevertheless, the Porter Hypothesis might be valid for both of our technology options due to the secondary benefits of an innovation-friendly environmental policy: end-of-pipe technologies might increase, for instance, the competitiveness of an industry that is the forerunner of an international trend. If a country imposes a specific regulation on an industry that requires end-of-pipe investments, firms might have gained a competitive "first mover" advantage in the long run once other countries adapt the same regulation. Strict environmental regulations may also improve the competitiveness of firms in the long run by stimulating resource and cost-efficient, cleaner production measures.

Empirical evidence on this issue is rare due to a lack of technology specific firm data. By analyzing the effects of a German environmental investment program, HORBACH et al. (1995) show that in some cases process-integrated measures, as opposed to end-of-pipe technologies, lead to significant cost savings. The same results are obtained in a series of cases studies carried out by HITCHENS et al. (2003) for European SMEs. Furthermore, WALZ (1999) shows that the introduction of new, integrated technologies in order to curb CO_2 emissions may lead to an increase in total factor productivity. Finally, industry surveys conducted by PFEIFFER and RENNINGS (2001), RENNINGS and ZWICK (2002), and RENNINGS et al. (2003) confirm that environmental innovations have a small but nevertheless beneficial economic impact on sales and employment. It remains unclear whether such a small impact induces firms to shift their investments from end-of-pipe to cleaner production technologies.

Market-based instruments have been regarded as superior in the early environmental innovation literature with particular respect to the choice of the appropriate environmental policy instruments (DOWNING and WHITE, 1986, MILLIMAN and PRINCE, 1989). This characterization has been confirmed for situations of perfect competition and information. Yet, under conditions of imperfect competition, results originating from general equilibrium models of endogenous growth and game theory models suggest that regulation standards may be a more appropriate method for stimulating innovation, particularly when firms gain "strategic advantages" from innovation, see CARRARO (2000) and MONTERO (2002). Furthermore, when the endogeneity of technological progress is taken into account, as it is done in evolutionary economics as well as in the new institutional and growth theory[1], none of the policy instruments is generally preferable. According to FISCHER et al. (2003), the welfare gain of environmental policy instruments critically depends on the circumstances involved. FRONDEL et al. (2004a) find that generally policy stringency is more important than the choice of single policy instruments.

4 The OECD Data Set and Descriptive Results

In our analysis of different abatement technologies, we use a facility and firm-level data set established within a recent OECD survey on environmental policy tools and their impact on firm management practices in manufacturing. The survey was performed in 2003 and covers seven OECD countries: Canada, France, Germany, Hungary, Japan, Norway, and the USA. The whole data set includes 4,186 observations originating from manufacturing facilities with more than 50 employees. The questionnaire contains questions on the facilities' environmental impacts, their motivations for the implementation of environmental practices and abatement technologies, the influence of stakeholders, management systems as well as of the environmental policy framework, and, last but not least, facility-specific structural characteristics (for more details, see the description of our variables provided in Section 5 and the Appendix).

Table **1** indicates that 3,100 of our sample facilities, that is around 74%, took significant technical measures to reduce the environmental impacts associated with their activities. Out of these facilities with altered production processes 76.8% changed their production technologies and only a minority of about 23% implemented end-of-pipe technologies. This is a surprising result, since it is a widespread assumption that end-of-pipe technologies still dominate investment decisions in firms. Recent surveys, though, indicate that cleaner production innovations have almost caught up, see the German survey by CLEFF and RENNINGS (1999), or even exceeded the share of end-of-pipe innovations, see the survey by RENNINGS and ZWICK (2002) for the European context.

Table 1: Distribution of Abatement Technology Types in our Sample Facilities in 2003

Cleaner Production Measures	2380	76.8%
End-of-Pipe Technologies	720	23.2%
Total	3100	100%

[1] For a comprehensive summary, see AGHION and HOWITT 1998.

Regarding the introduction of product or process innovations, the respondents of our sample firms indicated which of these innovation types they use predominantly. Not surprisingly, most facilities report that they took more significant measures in the area of production processes than in product design (see Table 2).

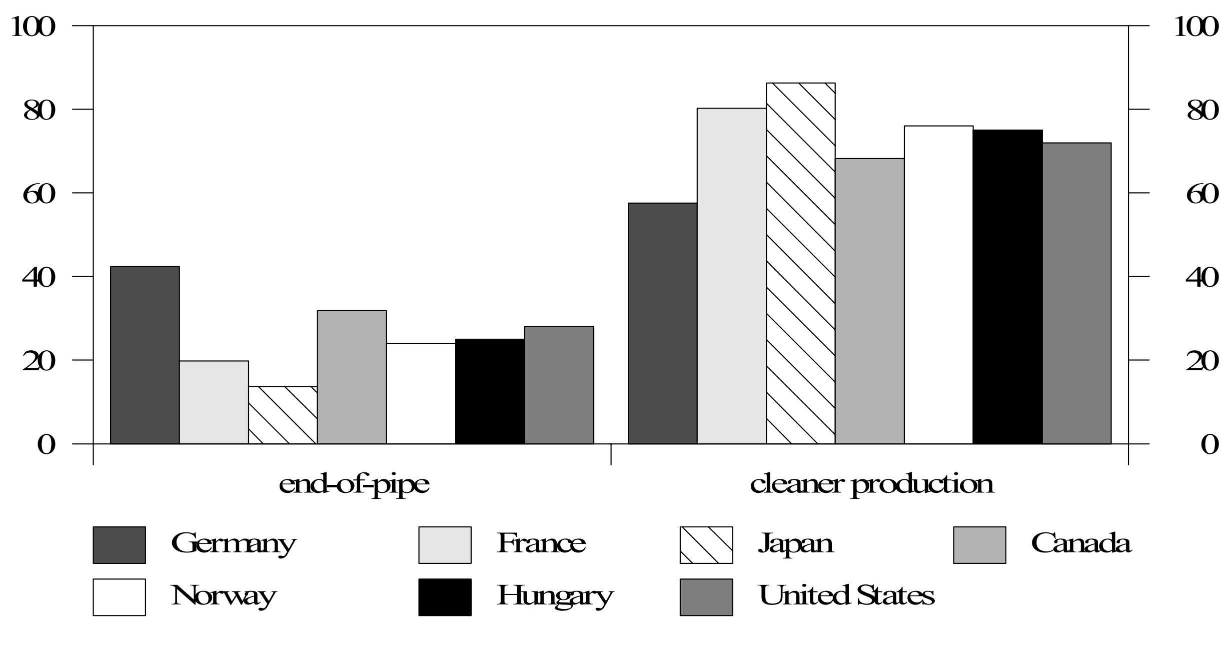
Table 2: Distribution of Product and Process Innovations in our Sample Facilities

Product Innovations	486	15.6%
Process Innovations	2632	84.4%
Total	3118	100%

There are, however, significant differences among the interviewed OECD countries. Most notably, Germany displays the lowest percentage of cleaner production technologies among the seven OECD countries (see Figure 3).

Figure 3: Choice of Environmental Technologies in Seven OECD Countries

In %

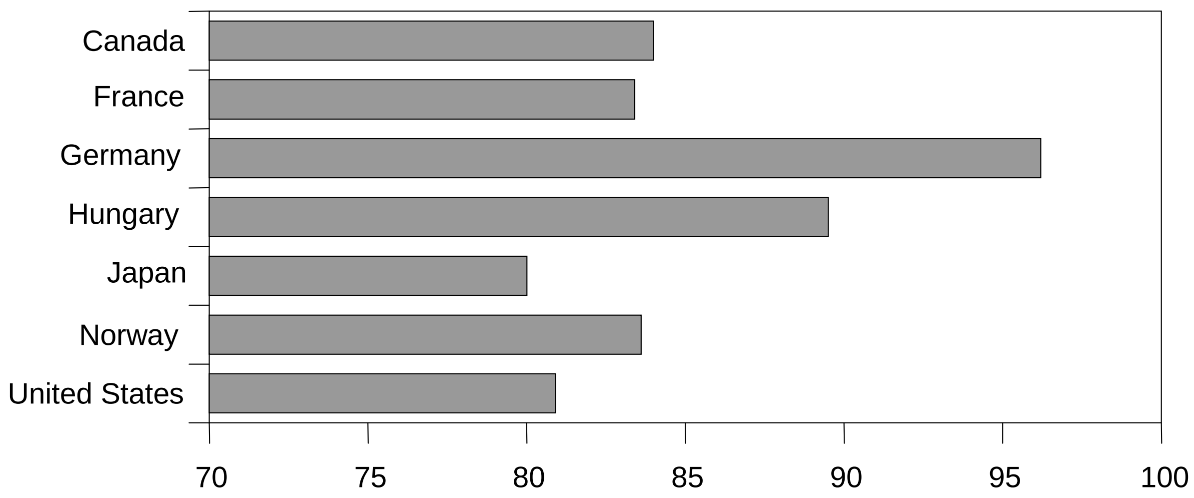


The share of cleaner production technologies ranges from 57.5 % in Germany to 86.5 % in Japan (for more details on the German data, see FRONDEL et al., 2004b). The reason for this result is that CaC heavily supported end-of-pipe technologies in Germany in the past (HAUFF und SOLBACH, 1999). But recent empirical results point to a growing importance of cleaner technologies in Germany (see HORBACH 2003a and 2003b).

While a large majority of our sample facilities reports that the established measures to reduce environmental impacts tend to aim at production processes and not at products, Germany and Hungary exhibit the lowest proportion of facilities stating that they implemented product measures (see Figure 4). These results are in line with findings of recent surveys in Germany (e.g. REHFELD et al., 2004) and Europe (RENNINGS and ZWICK, 2002). These surveys confirm the general view that rate and direction of environmentally benign technological progress differ according to the type of innovation. While pollution problems have been countered quite successfully through the use of cleaner processes at the production site, product integrated environmental innovations still suffer from poor market incentives (RENNINGS et al., 2004b). The crucial problem still seems to be that environmental innovations are not scaled up from niche markets to mass markets (take-off phase).

Figure 4: Incidence of Measures Undertaken (Production rather than Product)

In %



5 Determinants of Technology Choice End-of-pipe vs. Cleaner Production

Using an unordered multinomial logit model, i.e., discrete choice methods, we analyze why firms decide to introduce different abatement technologies. On the basis of the OECD firm and facility-level data set summarized in the previous section, we capture a firm's decision on a specific environmental abatement technology by applying the categorical variable *choice*, which reflects three distinct unordered abatement choices:

(1) end-of-pipe technologies,

(2) cleaner production technologies, and

(3) the no-abatement option – no new environmental technologies are implemented.

Respondents of our sample firms indicated which of these technology types characterized the nature of their abatement measures most accurately. While a firm may use both types of technology, our categorical variable *choice* reflects the technology that is predominantly employed by a firm. Clearly, this variable may suffer from the fact that the identification of process-integrated technologies is rather difficult, because they can be easily confused with ordinary production processes. Another problem results from the fact that firms sometimes cannot easily choose between end-of-pipe technologies or integrated measures – a problem that is based on technological restrictions. Our econometric model addresses this issue by using dummies for branches, because some types of technological abatement options may be industry-specific (see the discussion on sector-specific modes of innovative search outlined in Section 3).

The individual decision of a facility to opt for one of the three abatement alternatives depends on factors that are divided into the following five categories[2]:

(1) *Motivations*: This category captures the goals of environmental protection activities, such as expected corporate *image* improvements, *cost savings* due to the implementation of abatement technologies or potential avoidance of environmental *incidents*. (*Italic terms* stand for the names of the variables used in the tables presenting our estimation results).

(2) *Environmental policy instruments*: This category comprises respondents' assessment of the importance of *market*-based instruments, such as environmental taxes, *regulatory measures* (input bans and technology standards), *information* measures, and *subsidies*. The stringency of a government's environmental policy may also foster abatement decisions. The variable *policy stringency* describes respondents' perception of the stringency of environmental regulation.

(3) *Management tools*: Different management practices, such as *health and safety* management *systems* and *process or job control systems*, may have distinct implications for the choice of abatement technologies. Process control systems, for instance, may help identify energy saving potentials by controlling the whole production process and thus may serve as an information basis for the design of cleaner technologies. This may also be true for specific environmental management tools, such as *written environmental policies*, *internal* environmental *audits*, *environmental accounting*, and public environmental *reports*. In many cases, the firms need sufficient information about the environmental impacts at each phase of the

[2] All variables are constructed from the answers provided by the survey respondents. This approach is far from unproblematic, since these responses reflect both genuine variations across facilities and individual differences in the perception of the respondents. For descriptive statistics and details on construction, see the Appendix.

production process so as to implement cleaner technologies. Environmental management practices may help to provide this information basis.

(4) *Pressure groups*: This category reflects the –influence of interest groups – as perceived by the survey respondents – such as industrial associations and labor unions (summarized in the variable *unions)*, *internal forces*, such as corporate headquarters and management employees, commercial and private *customers*, and environmental (*green*) *org*anization*s*.

(5) *Facility Characteristics*: Abatement decisions may be affected by a set of facility-specific covariates that are discussed in the literature review provided in Section 3. Such covariates are, for instance, facility *size* and *turnover*, measured in terms of number of employees and sales, respectively. Finally, the relevance of environmental *impacts* of any kind of pollution and a person explicitly responsible for environmental concerns, identified as *officer*, might also be relevant. Furthermore, a specific research and development budget for environmental matters (*R&D*) was used as an indicator for the respective technological capabilities. Quantitative indicators for research and development were not available due to a high number of missing values. The influence of the market structure was captured in the variable *competition* reflecting the number of competitors of the responding firm.

Estimation results for our multinomial logit model are reported in Table 3 and indicate a significant, positive correlation of environmental policy stringency with the introduction of end-of-pipe technologies, but not with cleaner production. This result is perfectly in line with recent theoretical research on the innovation effects triggered by various environmental policy instruments described in Section 3, which suggests that policy stringency is more important than the choice of a single environmental policy instrument. While theoretical considerations would expect that a strict environmental policy would have a significant effect on both end-of-pipe technology and cleaner production, the relative importance of policy stringency for end-of-pipe technologies might be explained by the fact that CaC is still the dominating environmental policy. Cleaner production measures, however, tend to be stimulated by other factors than CaC.

This interpretation is in accordance with the observed differences in the impacts of environmental instruments: The implementation of end-of-pipe measures seems to be fostered by input bans and technology and performance-based standards, whereas the respective variable *regulatory measures* is not significant for the introduction of cleaner production technologies. This result might be explained by the fact that cleaner production measures have been less subject to environmental regulations so far.

Table 3: Multinomial Logit Model of Available Abatement Options

	End-of-pipe	Cleaner Production
	Environmental Policy	
Policy Stringency	1.43 (2.15)*	1.22 (1.27)
Regulatory Measures	1.34 (2.11)*	1.14 (1.12)
Market Instruments	1.30 (1.86)	1.06 (0.47)
Information	0.82 (-1.13)	0.80 (-1.48)
Voluntary Measures	0.90 (-0.52)	1.02 (0.12)
Subsidies	1.08 (0.46)	1.15 (0.97)
	Pressure Groups	
Internal Forces	1.43 (2.60)**	1.52 (3.57)**
Unions	0.65 (-1.92)	0.84 (-0.88)
Green orgs	1.01 (0.09)	0.96 (-0.32)
	Management Tools	
Health and Safety System	1.29 (1.98)*	1.44 (3.49)**
Process or Job Control System	1.13 (0.85)	1.33 (2.35)*
Written Environmental Policy	1.45 (2.42)*	1.52 (3.31)**
Internal Audits	1.26 (1.53)	1.58 (3.72)**
Environmental Accounting	2.00 (4.05)**	1.71 (3.52)**
and Reports	1.28 (1.56)	1.52 (2.98)**

	End-of-pipe	Cleaner Production
	Motivations	
Image	1.03 (0.18)	1.10 (0.84)
Incidents	1.47 (2.85)**	1.37 (2.88)**
Cost Savings	1.23 (1.63)	1.62 (4.53)**
	Facility Characteristics	
Competition	0.91 (-0.79)	1.02 (0.15)
Impacts	1.78 (4.34)**	1.40 (2.95)**
Officer	2.11 (4.86)**	1.63 (4.07)**
R&D	1.31 (1.03)	1.75 (2.47)*
Size	1.00 (-0.27)	1.00 (-1.95)*
Turnover	1.07 (0.51)	1.02 (0.23)
	Country Dummies	
Germany	0.28 (-4.76)**	0.21 (-6.62)**
France	0.56 (-1.76)	1.34 (1.06)
Hungary	1.79 (1.91)	2.37 (3.27)**
Japan	1.54 (1.59)	4.92 (6.93)**
Norway	0.92 (-0.26)	1.15 (0.53)
USA	1.73 (1.76)*	2.20 (2.81)**
	Industry Dummies	
Textile	0.79 (-0.81)	0.61 (-2.01)*
Wood	0.50 (-2.22)*	0.70 (-1.39)
Paper	0.92 (-0.30)	0.92 (-0.36)
Chemicals	0.77 (-1.14)	0.77 (-1.28)
Minerals	1.46 (1.14)	1.17 (0.51)
Metals	0.84 (-0.79)	0.94 (-0.34)
Machines	0.37 (-4.43)**	0.57 (-3.13)**
Transport	0.42 (-2.96)**	0.58 (-2.28)*
Other sectors	0.79 (-0.53)	0.86 (-0.40)

Number of observations: 3699. χ^2 (78) = 1267.71. Pseudo R^2 = 0.178. The base category is "no abatement technology".. Z-statistics are given in parentheses; * and ** denote significance at the 5% and 1% level, respectively., Odds ratios for one unit changes in the corresponding variables are reported instead of coefficients.

An important assumption of multinomial logit models is that outcome categories have the property of independence of irrelevant alternatives (IIA). The results of Hausman/McFadden tests have shown that there is no systematic change in the coefficients if we exclude one of the alternatives.

Surprisingly, there is no significant impact of market-based environmental instruments, a result that is explained by the fact that policy instruments do not have a significant impact if their implementation is lax. Particularly market-based instruments, such as eco-taxes, are often watered down in the political process. Another result suggests that innovations in cleaner production technologies tend to be market-driven and not so much regulation-driven: cost savings tend to favor process-integrated measures and not end-of-pipe technologies.

This result supports the view that the nature of integrated technologies often leads to energy and/or material savings as well as *cost savings*. Furthermore, technological capabilities seem to be more important for cleaner technologies than for end-of-pipe measures. The respective variable *R&D* is only significant for cleaner technologies.

Not surprisingly, the occurrence of environmental incidents spurs the introduction of both technology types. Among pressure groups the *internal forces*, such as corporate headquarters and management, have statistically significant positive effects on the implementation of environmental technologies, be it end-of-pipe or cleaner production technologies. External forces, such as labor unions (*unions*) or environmental or neighborhood groups (*green orgs*) do not seem to be influential with respect to either decision.

Furthermore, (environmental) management tools appear to be particularly important for the introduction of clean technologies. *Process or job control systems* significantly promote the implementation of integrated technologies. It seems to be plausible that *internal* environmental *audits* and the preparation of environmental *reports* are not significantly important for end-of-pipe measures but for cleaner technologies, since both policy tools may help to get the information required for cleaner technologies. The implementation and operation of cleaner technologies is often more complex than for end-of-pipe-technologies. In contrast, *environmental accounting* and a *written environmental policy* seem to favor the realization of both types of abatement technologies. One explanation might be that environmental accounting reveals the facilities' problems in this area, which may lead to, first, the documentation of both environmental problems and solutions and, second, to abatement actions, irrespective of the type of technology options.

Our estimation results indicate that the high importance of environmental *impacts* for firms is positively correlated with the realization of environmental investment – indeed, no surprising result. The introduction of both types of abatement measures is significantly promoted if at least one employee is explicitly responsible for environmental concerns, indicated by the dummy variable *officer*. Estimation results for the industry dummies, which capture the distinct technological options across industries, confirm our expectation that the implementation of cleaner production and end-of-pipe measures varies across branches.

6 Product versus Process Innovations

In this section, we investigate a firm's decision to introduce environmental product innovations by applying a binary probit model. Because of the violation of the IIA assumption, we will not estimate the same multinomial model as in the previous section, which showed process- and product innovations versus the no-abatement alternative. Instead, we analyze a firm's binary decision to introduce product instead of process innovations: Respondents of our sample facilities indicated which type of technology was implemented and reflects the nature of their environmental innovations, product or process innovations of their firm most accurately.

Table 4: Probit Model of the Available Product Innovations (1) versus Process Innovations (0).

	Environmental Policy		Motivations
Policy Stringency	-0.02 (-0.81)	Image	0.03 (1.62)
Regulatory Measures	0.02 (1.25)	Incidents	-0.01 (-0.82)
		Cost Savings	0.01 (0.44)
Market Instruments	-0.02 (-0.96)		Facility Characteristics
Information	0.01 (0.50)	Competition	0.01 (0.32)
Voluntary Measures	0.00 (0.17)	Impacts	-0.01 (-0.68)
		Officer	-0.02 (-1.19)
Subsidies	0.02 (0.80)	Primary customer	0.01 (0.40)
		R&D	0.01 (0.32)
		Size	-0.00 (-1.30)
		Turnover	-0.02 (-1.07)
	Pressure Groups		Country Dummies
Internal Forces	-0.01 (-0.38)	Germany	-0.11 (-3.73)**
Customers	0.02 (1.13)	France	0.01 (0.27)
Unions	-0.01 (-0.42)	Hungary	-0.07 (-2.33)*
Green orgs	-0.01 (-0.45)	Japan	0.01 (0.35)
		Norway	-0.00 (-0.06)
		USA	0.04 (1.08)
	Management Tools		Industry Dummies
Health and Safety System	-0.00 (-0.00)	Textile	0.13 (2.63)**
		Wood	0.16 (3.40)**
Process or Job Control System	-0.00 (-0.18)	Paper	0.12 (2.90)**
		Chemicals	0.13 (3.78)**
Written Environmental Policy	-0.02 (-0.94)	Minerals	0.09 (1.76)
		Metals	0.06 (1.97)*
Internal Audit	0.01 (1.28)	Machines	0.13 (3.96)**
Environmental Accounting and Report	-0.03 (-1.50)	Transport	0.08 (1.87)
		Other sectors	0.14 (2.16)*
	-0.00 (-0.03)		

Number of observations: 2776. χ^2 (41) = 126.97. Pseudo R^2 = 0.053. Z-statistics are given in parentheses; * and ** denote significance at the 5% and 1% level, respectively. Marginal effects are reported instead of coefficients.

Apart from country and industry-specific differences, the determinants of our estimation results[3] do not show any difference between the two innovation decisions (see Table 4). In short, the determinants of product and process innovations appear to be quite similar. This outcome might be explained by the fact that there is a wide overlap between these two types of innovations, which becomes obvious when taking a closer look at the European Commission's definition of product-integrated environmental innovations.

According to this definition (see EC 2001 and 2003), environmental product innovations include process changes "from cradle to grave", in other words, an improvement of the environmental performance of products including the selection of raw materials or supplied parts, the research and development phase, as well as the production, consumption, and disposal phases.

7 Summary and Conclusions

This paper analyzes factors that may enhance a firm's propensity to implement cleaner products and production technologies rather than end-of-pipe technologies. While both of these two fundamental types of abatement measures mitigate the adverse environmental impacts of production, cleaner production technologies are frequently more advantageous than end-of-pipe technologies for both environmental and economic reasons. In fact, environmental innovations are more often identified with cleaner production measures than with end-of-pipe technologies, which reduce environmental impacts by using add-on measures without changing the production process.

Nevertheless, it is a widespread assumption that end-of-pipe technologies still dominate investment decisions in firms. This is because there has been exceptionally little empirical analysis directed to the determinants of the use of specific types of abatement measures - principally because of the paucity of available data. On the basis of a unique facility-level data set based on a recent survey covering seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway, and the U.S.) we find a clear dominance of cleaner production in these countries: Surprisingly, 76.8% of our sample facilities report that they predominantly invest in cleaner production technologies. There are, however, significant differences: Most notably, Germany displays the lowest percentage of cleaner production technologies among these OECD countries (57.5 %), while Japan exhibits the highest respective share (86.5 %).

[3] Note that product design is likely to be within the responsibility of a firm and not so much of a facility. While attempting to take account of this aspect by including a binary variable in our model that indicates whether or not a facility belongs to a multi-facility firm, we were unable to find a significant impact of this variable due to the corresponding high number of missing values.

The explanation is that Germany's command and control policy heavily supported end-of-pipe technologies in the past. Recent empirical results, however, point to a growing importance of cleaner technologies in Germany.

Our estimation results, which are based on multinomial logit models, indicate that cost savings tend to favor clean production and that regulatory measures and the stringency of environmental policy are positively correlated to end-of-pipe technologies. These results suggest that the application of end-of-pipe measures depends at least partially on regulatory pressure, whereas cleaner production may be motivated – among other factors – by market forces. Furthermore, we find empirical evidence that organizational innovations improve the technological capabilities of facilities: General management systems and specific environmental management tools such as process control systems or environmental audits seem to support the implementation of cleaner production measures, presumably by improving the necessary information basis for the development of such technologies. We thus conclude that improvements towards cleaner products and production may be achieved by developing and disseminating these management tools to a larger extent. Furthermore, the introduction of cleaner technologies and products is supported by R&D investment specifically related to environmental matters.

With particular respect to environmental product innovations, we find that a large majority of facilities in these OECD countries report that their measures are aimed at production processes and not so much at products to reduce environmental impacts. While pollution problems have been mastered quite successfully through the use of cleaner processes at the production site, product-integrated environmental innovations still seem to suffer from poor market incentives. Our estimation results based on a binary probit model indicate that the determinants of environmental product innovations are quite similar to those of process innovations. This might be explained by the fact that product-integrated environmental innovations include process changes "from cradle to grave", in other words, there is a wide overlap between these two types of innovations.

We conclude that additional investments in cleaner production and products may be stimulated by widening the cost gap between the two types of technologies, for instance, by additionally charging for the use of waste and energy. The potential for continuously substituting end-of-pipe technologies with cleaner technologies might be limited, however, since not all regulations favoring end-of-pipe technologies can be cut down. For example, additional filters currently reduce particulate emissions of Diesel cars more effectively than the more eco-efficient Diesel engines. Thus, a certain amount of end-of-pipe technologies will still be necessary to curb specific emissions which cannot easily reduced with cleaner production measures.

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Appendix: Description and Descriptive Statistics of Variables.

Name of variable	Description	Mean	Std. Dev.
Choice	End-of-pipe or integrated (change in processes) technologies (1 end-of pipe, 2 integrated, 3 no new technology)	---	---
Motivations for environmental activities	The variables get the value 1 when "very important" was chosen, and 0 for other categories		
Incidents	Prevent or control environmental incidents	0.57	0.50
Image	Corporate profile/image	0.46	0.50
Cost Savings	Cost savings	0.43	0.50
Environmental policy instruments			
Policy Stringency	Stringency of environmental policy (1 stringent, 0 not or moderately stringent)	0.17	0.37
	The following variables get the value 1 when "very important" was chosen for at least one of the items, and 0 for other categories:		
Regulatory Measures	Input bans, technology and performance standards	0.43	0.50
Market Instruments	Taxes, tradable permits, liability for environmental damages	0.47	0.50
Information	Information measures for consumers and buyers	0.15	0.36
Voluntary Measures	Voluntary or negotiated agreements	0.11	0.31
Subsidies	Subsidies, tax preferences, technical aid programmes	0.18	0.39
Management tools			
Health and Safety System	Health and safety management system (1 yes, 0 no)	0.56	0.50
Process or Job Control System	Process or job control system (1 yes, 0 no)	0.44	0.50
Written Environmental Policy	Written environmental policy (1 yes, 0 no)	0.58	0.49
Internal Audit	External environmental audits (1 yes, 0 no)	0.57	0.50
Environmental Accounting	Environmental accounting (1 yes, 0 no)	0.30	0.46
Environmental Report	Public environmental report (1 yes, 0 no)	0.25	0.43
Role of interest groups and organizations	The variables get the value 1 when "very important" was chosen for at least one of the items, and 0 for other categories		
Internal Forces	Corporate headquarters, management employees, shareholders	0.49	0.50
Authorities	Public authorities	0.44	0.50
Customers	Consumers, commercial buyers, suppliers, banks	0.36	0.48
Unions	Industrial associations, labour unions	0.10	0.31
Green Orgs	Environmental organizations, neighbourhood groups	0.22	0.41
Facility Characteristics			
Impacts	Importance of environmental impacts (1 very negative impacts, 0 other)	0.34	0.47
Officer	Existence of a person explicitly responsible for environmental concerns (1 yes, 0 no)	0.70	0.46
Size	Number of full time employees in the last three years	332.0	855.9
Turnover	Change of turnover in the last three years (0 if it decreased or stayed about the same, 1 if it increased)	0.33	0.47

List and explanation of variables (continued)

Name of variable	Description	Mean	Std. Dev.
Industry dummies			
Food	Food products, beverages and tobacco	0.10	0.30
Textile	Textiles, textile products, leather and footwear	0.05	0.22
Wood	Wood and wood products, furniture	0.05	0.22
Paper	Pulp paper, paper products, printing and publishing	0.08	0.27
Chemicals	Chemicals, fuel, rubber and plastic products	0.15	0.36
Minerals	Other non-metallic mineral products	0.04	0.19
Metals	Basic metals and fabricated metal products	0.20	0.40
Machines	Machinery, electrical and optical equipment	0.24	0.43
Transport	Transport equipment	0.07	0.25
Other sectors	e. g. recycling	0.02	0.14
Countries			
Canada	1 Canada, 0 Other countries	0.06	0.24
France	1 France, 0 Other countries	0.06	0.25
Germany	1 Germany, 0 Other countries	0.22	0.41
Hungary	1 Hungary, 0 Other countries	0.11	0.32
Japan	1 Japan, 0 Other countries	0.36	0.48
Norway	1 Norway, 0 Other countries	0.07	0.26
USA	1 USA, 0 Other countries	0.12	0.32

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