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# Determinants and Specificities of Eco-innovations – An Econometric Analysis for the French and German Industry based on the Community Innovation Survey

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## Déterminants et spécificités des éco-innovations en France et en Allemagne : Une analyse économétrique à partir de l'enquête Innovation Européenne

**Résumé**

*Cet article présente une étude économétrique comparative des déterminants et des spécificités des éco-innovations en France et en Allemagne. Dans la littérature, il existe peu d'études comparant les éco-innovations aux innovations en général et permettant une comparaison internationale. A partir des résultats de l'enquête innovation européenne (CIS) pour la France et l'Allemagne, nous proposons d'utiliser un modèle économétrique unifié pour les deux pays afin d'étudier les caractéristiques des éco-innovations et de mettre en évidence des faits stylisés communs aux deus pays considérés. Les résultats confirment le rôle central de la réglementation et des économies de coûts comme facteurs déterminants des éco-innovations. Ils montrent également que les éco-innovations sont plus intensives en information et en connaissances (en particulier de sources externes) que les innovations en général, et que les firmes éco-innovantes tendent à déposer plus de brevets que les autres firmes innovantes.*

**Mots-clés** : Eco-innovation, industrie, modèle Probit

## Determinants and Specificities of Eco-innovations – An Econometric Analysis for the French and German Industry based on the Community Innovation Survey

**Abstract**

*Many recent papers deal with exploring and explaining the determinants of eco-innovations for different countries supporting the formulation of efficient policy measures to trigger eco-innovation activities of firms. Unfortunately, there is still a lack of cross-country analyses allowing recognizing "international" stylized facts, but also regional characteristics of eco-innovations. Based on data from the fourth Community Innovation Survey (CIS) for France and Germany, the present paper tries to contribute to fill this gap. Using econometric methods, we are able to detect remarkable similarities between the different determinants of eco-innovation in the two countries. The results confirm the central role of regulation and cost savings as motivations for eco-innovation. Furthermore, eco-innovative activities seem to require more external sources of knowledge and information than innovation in general.*

**Keywords:** Eco-Innovation, Industry, Discrete Choice Models

**JEL: Q55, O33, O38, C25**

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# 1 Introduction[1]

On the background of global warming and a growing scarcity of energy and resources, eco-innovations are more and more in the focus of environmental policy and innovative strategies of firms. In contrast to other innovations, eco-innovations may even lead to a so-called ‘win-win’ situation characterized by both economic and environmental benefits due to the characteristic positive spillovers of these innovations that are accompanied by the internalization of negative environmental effects. This "win-win" effect allows firms to combine their competitiveness objectives with environmental concerns (Porter and van der Linde, 1995).

Many recent papers deal with exploring and explaining the determinants of eco-innovations for different countries (see e.g. Horbach, 2008, 2010 for Germany or Mazzanti and Zoboli, 2006 for Italy) supporting the formulation of efficient policy measures for eco-innovation activities of firms. Unfortunately, there is still a lack of cross-country analyses allowing to recognize “international” determinants and stylized facts, but also regional characteristics of eco-innovations.

Using data from the fourth Community Innovation Survey (CIS) for France and Germany, the present paper tries to contribute to fill this gap. Even if it is not allowed for legal reasons to combine the data of the two countries in one data file allowing a direct comparison, we develop a fully harmonized model with the same variables for the two countries exploring the main specificities of eco-innovations with respect to other innovations. The results contribute to a better understanding of the determinants of eco-innovative activities of industrial firms.

France and Germany seem to be two interesting cases, because, on the one hand, they have a similar industry structure and a comparable development level. On the other hand, the German history of developing environmental regulations and standards with the respective consequences for the economy is older compared to the French one.

The paper is organised as follows: Section 2 contains a recent definition of eco-innovation and theoretical arguments helping to develop hypotheses on specific determinants and characteristics of eco-innovation, Section 3 presents the results of the harmonized econometric models for Germany and France, and Section 4 summarizes the main results and gives some policy recommendations.

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# 2 Specific characteristics and determinants of eco-innovations

## 2.1 Definition

In a very broad sense, eco-innovations can be defined as innovations that consist of new or modified processes, practices, systems and products which, in comparison to conventional innovation alternatives, benefit the environment and contribute to environmental sustainability (Rennings, 2000). Obviously, the positive environmental impact of innovation is the core element of the definition. But this environmental impact may be intentional or not, local or global, and more or less significant compared to current or conventional technologies. Many criteria may be used to evaluate the environmental impact of an innovation: greenhouse gases emissions, air pollution, energy use, water pollution, noise, waste generation and soil contamination. Given the number of environmental criteria, the global environmental impact of an innovation is very difficult to assess. Because of rebound effects, the use of an eco-innovation may not lead to an absolute reduction in environmental harm. The classical example is cost-saving innovations that have a rebound effect through increased expenditure. For that reason, eco-innovations cannot be defined in terms of absolute environmental impact, but in terms of relative impact in reference to alternative technologies.

These considerations lead to the following definition of an eco-innovation resulting from a recent EU project on Measuring Eco-Innovation (MEI, Kemp and Pearson, 2008):

*"The production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives"* (Kemp and Pearson 2008, p. 7).

With such a definition, eco-innovations correspond to a very heterogeneous set of innovations, since every process or product that is more resource efficient and/or less polluting is an eco-innovation. Moreover, the degree of novelty is considered at its minimum level, which is at the firm level. Consequently, this definition embraces all innovations that enable a firm to decrease, progressively or drastically, its negative environmental impacts through new products, processes, services or methods.

## *2.2 Determinants and characteristics of eco-innovations*

Since the 1990s, several empirical studies try to identify the role of regulation and other determinants of eco-innovations at the demand or supply side[2]. These research works are very heterogeneous in terms of methodologies and results, since one of the main difficulties is to find adequate data and indicators on eco-innovations[3]. Even if there are still some controversies on the effective impact of environmental regulation on innovation and on the most efficient policy instruments in terms of incentives, many references emphasize a positive correlation between innovation and regulation. These results tend to bring empirical support to the so-called Porter hypothesis according to which "…properly designed environmental standards can trigger innovation that may partially or more than offset the costs of complying with them" (Porter and van der Linde, 1995). Following these authors, eco-innovation activities are not a result of an optimization process. Firms do not detect the potential of

[2] For a survey on the empirical literature on eco-innovations, see Horbach (2008), Oltra (2008) or del Rio Gonzalez (2009).

[3] For a survey on the measuring of eco-innovations, see for example Arundel and Kemp (2009).

environmental innovations because they are "… still inexperienced in dealing creatively with environmental issues." Environmentally and economically benign innovations are not realized because of incomplete information, organizational and coordination problems (Porter and van der Linde, 1995, p. 99). Firms are not able to recognize the cost saving potentials (e.g. energy or material savings) of environmental innovation. Therefore, environmental regulation may "force" firms to realize economically benign environmental innovation and, in that sense, act as "focusing devices".

In spite of the incentive role of regulation, eco-innovations cannot be considered to be a systematic response to regulation. Other factors linked to market conditions and to the technological capabilities of firms determine the technological response of regulated firms (see Table 1). As a matter of fact, an eco-innovation is primarily an innovation which depends, like all innovations, on a multiple set of factors. Since the 1980s, the evolutionary theory has developed a dynamic view of the technology which points out that the innovative process is highly path-dependent and cumulative (Dosi, 1988, Pavitt, 1984). Every firm tends to follow its specific technological trajectory depending on its technological capabilities and on its knowledge base. Firms build their base of knowledge, which is difficult to transfer (Levin et al, 1987), and so exhibit significant differences in terms of technological capacities (Galende and de la Fuente, 2003). Within the same line of inquiry, the resource-based approach of the firm[4] proposes an internal analysis of innovation which emphasizes the importance of the internal resources of firms (i.e. physical, financial, human and organizational resources) in explaining innovative behaviour (Wernerfelt, 1984; Barney, 1991). Overall, these approached highlight that many factors affect innovative process, not only factors external to the firm, but also its internal resources, and particularly, its experience, its knowledge base and its technological capabilities.

In this article, the determinants of eco-innovation are approached in accordance with the evolutionary theory of innovation and with the resource-based view of the firm, so that an extensive group of factors is considered (cf. Table 1). These factors are grouped into three categories, which are policy determinants, and the traditional supply side and demand side determinants. The significance of regulatory factors is one of the main specificity of eco-innovation compared to innovation in general. As a matter of fact, in spite of the controversies on the relative efficiency of environmental policy instruments, we can argue that the main specificity of eco-innovations, besides their positive impact upon environment, is linked to the determining role of regulation. This specificity is related to what is called the "double externality" problem. Eco-innovations produce two types of positive externalities: usual knowledge externalities in research and innovation phases, and externalities in the adoption and diffusion phases due to the positive impact upon environment. In other words, the beneficial environmental impact of eco-innovations makes their diffusion always socially desirable. This creates a twofold obstacle, or market failure, for firms to invest in eco-innovation since the private return on R&D is less than its social return. This double source of market failure justifies the needs of policy instruments and the existence of what Rennings (2000) calls the "regulatory push-pull" effect. This argument leads us to pose the following hypothesis to be tested in the econometric analysis:

[4] For a presentation of this approach, see for example Wernerfelt (1984) and Teece et al. (1997).

> H1 The main determinant of eco-innovation is the "regulatory push-pull effect" resulting from the implementation of environmental policy instruments.

But, the existence of this "regulatory push-pull" effect should not lead to consider eco-innovations as systematically induced by regulation, and so to under-estimate the role of supply and demand-side determinants. As shown in the literature, the environmental objective is generally not the direct and only purpose of eco-innovations, but comes in addition to other objectives. In more practical terms, it is obvious that firms try to comply with environmental regulatory requirements while following their main purposes in terms of competitiveness and productivity. As emphasized by Florida (1996), in their eco-innovative activities, firms have to combine several objectives and to find synergies between industrial and environmental performances. In that sense, an eco-innovation should not be considered as a completely different and specific innovation, but as the result of a search for technological compromises between various determinants and objectives. The capacity of firms to develop and to adopt eco-innovations depends on their ability to combine productive efficiency and product quality with environmental objectives[5] (Oltra and Saint Jean, 2005a, 2005b).

Several empirical studies stress that cost savings and productivity improvements are determining factors of eco-innovations, particularly for process innovations and clean technologies (see e.g. Rennings and Rammer, 2009). As emphasized by Frondel et al. (2007), innovation in clean technology tends to be driven both by cost savings and by regulation. This feature will also be tested in our econometric analysis with the following hypothesis:

> H2 Cost savings are one of the main objectives of eco-innovation activities of firms, particularly material and energy savings which trigger cleaner technologies.

Other empirical studies, in particular Mazzanti and Zoboli (2006), Rehfeld et al. (2007) and Wagner (2007), show that organizational innovations tend to be strongly correlated to eco-product and process innovations. The implementation level of environmental management systems seems to have a positive impact on eco-innovation. Very few empirical studies consider the role of “traditional” supply side determinants of innovations, like R&D activities, supply chain pressures or networking activities. Scott (2003) presents an econometric analysis of environmental R&D based on an original survey on the industrial R&D response of US manufacturing firms to the regulation of the emission of hazardous air pollutants. The author shows that on average 24 % of the industrial R&D performed by firms is related to improving the environmental performance of their products or processes, with a highest share linked to cleaner products. For France, the results published by IFEN (2008) show that, between 1990 and 2004, environmental R&D increased by 8% on average every year, but this trend tends to slow down since 2005. Globally, the role of R&D in eco-innovative activities is not well documented and it remains difficult to assess the share of specific environmental R&D.

[5] This capacity to combine multiple objectives is the necessary condition to achieve "innovation offsets" in the sense of Porter and van der Linde (1995).

**Table 1: Determinants of environmental innovation**

| | |
|---|---|
| Regulation and policy determinants | Implementation and institutionalisation of environmental policy instruments: economic and regulatory instruments<br>Regulatory design: stringency, flexibility, time frame<br>Anticipation of future environmental regulations |
| Supply side determinants | Technological capabilities: knowledge bases, R&D activities, human capital endowment<br>Cost savings, productivity improvements<br>Appropriability conditions, market structure<br>Organizational innovations: environmental management systems, extended producer responsibility<br>Industrial relationships, supply chain pressure, networking activities |
| Demand side determinants | Environmental consciousness and consumers' preferences for environmentally friendly products<br>Expected increase in market share or penetration of new market segments |

*Source: Horbach (2008), Oltra (2008).*

As to demand side determinants, it is generally assumed that market forces alone would provide insufficient innovation incentives and that consumers' willingness to pay for environmental improvements tends to be too low (Rennings, 2000). Nevertheless, several empirical studies try to identify and to evaluate the incentive effects linked to environmental pressure coming from consumers. According to Florida (1996), Popp et al. (2007) and Horbach (2008), customer demands and public pressure are essential drivers of eco-innovations. In comparison with non-environmental innovations, demand pull effects are strongly provoked or supported by environmental policies, such as regulations or taxes, that seek to affect the intrinsic and external (through incentive schemes) motivations of consumers. But as emphasized by Taylor et al. (2006), demand pull instruments shape more the adoption and the diffusion of environmental technologies, than the innovative activity itself[6].

The evolutionary approach to innovation (Nelson and Winter, 1982) emphasizes that firms and technologies differ greatly in terms of the knowledge base and learning processes related to innovation (Pavitt, 1984; Dosi, 1988; Malerba, 2005). Knowledge is considered to be at the basis of innovative activities which consequently depend on the capacity of firms to develop and to acquire new knowledge. This focus on knowledge lead some authors to emphasize that innovative activities rely on knowledge bases which are specific to sectors and to firms (Malerba and Orsenigo, 1996, 1997). These knowledge bases may have different sources (internal versus external to the firm or the industry) and different degrees of accessibility (according to their tacit or codified character). According to Malerba (2005), the knowledge base is "relevant for an explanation of the rate and direction of technological change, as well

[6] According to the definition of eco-innovation given in section 2.1, the adoption by a firm of a new eco-process is also considered to be an eco-innovation (e.g. even it is not developed internally by the firm). But this type of eco-innovation will not be included in our econometric approach since our data comes from the Comnunity Innovation Survey which only concerns innovation developed by firms.

as of the organization of innovation and production".

This argument leads us to question the knowledge bases underlying eco-innovation. What are the main sources of information used in eco-innovative activities? What are the main characteristics of the knowledge base in terms of nature and accessibility of knowledge? Is there a significant difference in the knowledge bases underlying eco-innovation and innovation in general? This issue of sources of information and knowledge used in eco-innovative activities is rarely treated in the eco-innovation literature. An exception is Rennings and Rammer (2009) which show that energy and resources efficiency innovation tend to be more complex innovation activities that require knowledge inputs from a diverse set of sources. They show (using innovation survey data) that German firms innovating in energy and resources efficiency more often use suppliers, competitors as well as universities and public research institutes, but that they also rely more strongly on internal sources. This result can be explained by the fact that eco-innovation may require knowledge and competences which do not belong to the core competences of firms i.e. the competences defining a firm's fundamental business (Teece et al., 1997). Except in eco-industries, whose core business is to develop environmental technologies, eco-innovation generally requires external knowledge and new competences linked to alternative production processes, inputs or materials. For that reason, we propose to explore the differences in the knowledge bases and in the sources of information between innovation in general and eco-innovation. The idea is that, since regulatory constraints tend to call into question firms' processes and knowledge bases, firms require, in order to adapt their processes and products, more external sources of knowledge and information for their eco-innovation activities than for other innovation. These external sources of information may come from suppliers, consulting firms or public research institutions. This leads us to a third hypothesis on eco-innovation which will be explored in our econometric study, notably by integrating variables concerning the main information sources used by firms in their innovative activities:

> H3 Eco-innovative activities require more external sources of knowledge and information than innovation in general.

The literature on innovation also stresses the role of appropriability of innovation, and particularly the role of patents. Even if patents provide imperfect and non-exhaustive data on innovation, they are widely used to capture innovative strategies of firms[7]. With the development of extensive and accessible patent databases, several authors have analyzed the micro-determinants of innovation using patent indicators as a measure of innovative output (e.g Cohen et al., 2000). Most of these studies have focused on traditional determinants of patenting behaviour, such as firm size, market power, technological opportunities and R&D efforts. Even if the effect of firm size and market power is still controversial, the empirical literature tends to show a positive correlation between firm size (and market power) and the propensity to patent. As to the relationship between R&D and patent, it can be seen as a virtuous circle which is conducive to a positive and significant relationship well documented in the literature (Peeters and van Pottelsberghe, 2006). Two variables that are also traditionally included in patent equations are market and technological opportunities. Firms in high technological opportunity sectors are found to patent more than others (Crépon et al., 1996; Brouwer and Kleinknecht, 1999), but the difference is not always significant.

In the field of eco-innovation, even if it remains difficult to identify eco-patents[8], OECD data show a significant increase in patenting activity since 2000 in the field of environmental

[7] For a survey, see Griliches (1990).
[8] For a survey on that question, see Oltra et al. (2010).

technology, more particularly in energy, waste and automobile pollution control technology (OECD, 2008). Following Porter's hypothesis, we can argue that environmental regulation creates new technological and market opportunities which tend to increase eco-patenting. Moreover, this trend can also be explained by the fact that eco-innovations are generally linked to rather new and young technologies which are likely to open new market opportunities and to create comparative advantage. For all these reasons, we argue that firms' propensity to patent is higher for eco-innovation than for normal innovation. This is the last hypothesis to be tested in our econometric analysis:

> H4 Firms tend to protect more intensively their eco-innovations than other innovations, in particular through patents.

# 3 Econometric analysis of the determinants of eco-innovations in Germany and France: A synthesis model

## 3.1 Methodology and variables

The purpose of the econometric estimations presented in this paper is to evaluate the specific determinants of eco-innovations (in comparison with innovation in general) on the basis of the Community Innovation Survey (CIS 4 for the period 2002-2004) and to compare the results between France and Germany. The CIS is not specifically designed to explore eco-innovations, but it includes a question on the environmental impact of innovation. In our analysis, this question serves to define a filter variable separating eco-innovations and other innovations. Following the definition given in Section 2, it allows analyzing the determinants of the (perceived) environmental effects of innovation activities including product and process innovations. Unfortunately, the questionnaires of France and Germany differ concerning this question. The French survey also includes the impact upon health and safety, while in Germany, health and safety aspects are treated separately. To establish comparability of the French and German results, in a first step, we include the health and safety aspects in the estimations for Germany. In a second step, we estimate the same model for Germany, but only regarding the environmental effects to find out if there are systematic differences (see Appendix 2 for the results of this model).

Due to the fact that the dependent variable is binary, a probit model is used[9] that can be briefly described as follows: The firm has to decide whether to introduce an environmental innovation (Y = 1), or an "other innovation" (Y = 0). Following our theoretical considerations, we believe that different factors such as regulation or cost savings summarized by a vector **x** influence this decision. Therefore, we need an estimation of the following probability:

$\text{Prob}\ (Y = 1|\ \mathbf{x}) = F\ (\mathbf{x}, \beta)$.

Because of the binary character of our dependent variable, we use the probit model assuming the normal distribution: $\text{Prob}\ (Y = 1|\ \mathbf{x}) = \varphi\ (\mathbf{x}'\ \beta)$

The parameters β reflect the impact of changes in x on the probability (Greene, 2008, p.772).

We calculate marginal effects that allow comparing the results for France and Germany. In order to focus on industrial firms, we choose to restrict our sample to industrial sectors, so excluding services sectors.

Our binary dependent variable *ecoinnovation* gets the value 1 if the innovation activities of

[9] For a detailed description of this model see e.g. Greene (2008).

the firm led to high or medium reduction of environmental pollution and/or health and safety effects and 0 otherwise. Following this definition including health and safety effects, the French (German) sample contains 1782 (776) eco-innovative companies and 1639 (1190) other firms. Restricting the definition to the mere environmental effects what is only possible for Germany leads to 572 eco-innovative firms and 1393 firms that realized other innovations.[10]

Our correlated variables describing relevant determinants of the different types of innovation can be classified into the following eight categories: policy measures; market pull and technological push determinants; market characteristics; innovative activities; barriers to innovation; information sources; appropriability conditions; and sectoral variables.

The **policy measures** are captured by the variables *regulation*, *subsidies* and *PACE*. *Regulation* describes the fulfilment of regulations and standards as an effect of the innovation.[11] *Subsidies* gets the value 1 if the firm got financial aid from public institutions and zero otherwise. *PACE* denotes the pollution abatement expenditures (sectoral average level) and is calculated for each industry sector included in our analysis. The role of this variable is twofold: on the one hand, it controls for sectoral differences, on the other hand, it may also be interpreted as a proxy for the stringency of regulation activities (see e. g. Brunnermeier and Cohen, 2003).

Furthermore, we try to find out if market and technological forces ("**market pull and technological push**") are relevant for eco-innovation. Especially cleaner technologies are often motivated by the possible perspective of cost savings (*MatEnergySav.*), so that we also included the corresponding variable (see also Frondel et al. 2007). To explore further differences between eco-innovations and other innovations, we include the increase in *market* share, the improvement of product quality (*prodquality*) and of production *(flexibility)* as innovation effects.

**Market characteristics** can be approached through the following variables: the size of firms *(size)*, the geographic market on which firms sell their products i.e. local *(LocalMarket)*, national *(NatMarket)*, European *(EurMarket)* or other foreign countries *(OtherMarket)*, the competitive pressure coming from established firms *(Barrierestablish)* and the uncertainty on demand *(UncertaintyDde)*.

Concerning the variables characterizing **innovative activities**, we include the distinction between product and process innovations *(Product, Process)* and the role of marketing *(Marketing)* innovations. We also include in the model the expenditure linked to innovation, i.e. internal *R&D* and investments in external knowledge *(InvExtKnow)*. Furthermore cooperation (*coop*) activities are considered.

For the **barriers to innovation**, we consider two variables: cost factors *(BarrierCost)* and lack of knowledge *(BarrierKnow)* that hinder the realization of innovations.

As to **information sources** supporting the innovation performance of a firm, we include the influence of the different sources *(InternInfo, SupplierInfo, ClientInfo, CompetitorInfo, ConsultInfo, Universities, PublicInfo)* and information from conferences *(infoconference)*.

The CIS database also allows exploring the **appropriation** tools and mechanisms applied by

[10] The reduction of cases in the probit model (see Table 2) is due to missing values in the different variables.

[11] Due to data restrictions we use the fulfilment of regulations as innovation effect as a proxy for the respective motivation to introduce the innovation. In fact, this is a useful procedure because it seems to be unrealistic or rare that innovations that resulted in fulfilling regulations did not have the motive to do that. Please also note that this indicator is subjective because it only describes the perceived role of regulations. Therefore, we also use PACE as a more objective stringency indicator.

the innovating firms in the sample. The use of *patent*s, the enforcement of a *copyright*, the *secrecy* of inventions, the *complexity* of design or a *time lead* with regard to competitors may be analyzed.

In our econometric analysis, we renounced to use sector dummies but we tried to capture **sectoral specificities** by the following control variables: PACE denoting the pollution abatement cost expenditures of each sector and the Herfindahl Hirschman Index (*HHI*) as a concentration measure of the respective sectors in the sample.

## 3.2 Results of the econometric analysis

The following econometric analysis tries to assess empirically our theoretically derived main hypotheses. Table 2 summarizes these hypotheses by linking them to our empirical variables.

**Table 2: Empirical assessment of the main hypotheses**

| **Hypotheses** | **Variables within the econometric Analysis** |
|---|---|
| *H1*<br>The main determinant of eco-innovation is the "regulatory push-pull effect" resulting from the implementation of environmental policy instruments. | Regulation, subsidies, PACE |
| *H2*<br>Cost savings are one of the main objectives of eco-innovation activities of firms, particularly material and energy savings which trigger cleaner technologies. | MatEnergySav. |
| *H3*<br>Eco-innovative activities require more external sources of knowledge and information than innovation in general. | SupplierInfo, ClientInfo, CompetitorInfo, ConsultInfo, Universities,<br>Publicinfo, Infoconference |
| *H4*<br>Firms tend to protect more intensively their eco-innovations than other innovations, in particular through patents. | Patent, Copyright, Secrecy, Complexity, Timelead |

The results of the econometric analysis (see Table 3) show that, in both countries, the regulatory push-pull effect seems to be highly relevant for eco-innovations documented by the significance of the respective variable *regulation* strongly supporting the hypothesis H1. Moreover, the marginal effect of this variable is high in both countries. In Germany, furthermore, this result is also confirmed by the positive influence of PACE, denoting the pollution abatement expenditures of the sector the questioned firm belongs to. As already mentioned, PACE may be interpreted as an exogenous policy stringency indicator (see e.g. Brunnermeier and Cohen, 2003). But this variable does not have a significant effect in the French sample. As to *Subsidies,* it does not seem to be especially important for eco-innovations – a result that is valid for both countries.

Furthermore cost savings, especially material and energy savings (*MatEnergySav*) play a very important role in triggering eco-innovations in both countries supporting our hypothesis H2. The marginal effects of the respective variable are high (30% for France and 26% for

Germany). The results tend to corroborate that eco-innovations are more and more combined with efficiency objectives. On this point, the results illustrate empirically the idea that firms can find synergies between competitiveness objectives and environmental ones through eco-innovations. The results on the variable *Flexibility,* which is significant for both countries, support the same argument: through eco-innovation, firms can improve the flexibility of their production process. So we can argue that our sample brings support to the existence of significant 'process innovation offsets' in the sense of Porter and van der Linde (1995). In more practical terms, the results underscore that, in industrial sectors, process eco-innovations are conducive to materials and energy savings, decrease in production costs and improvements in production flexibility.

In the French sample, eco-innovations seem to be more oriented towards product and process innovations (and so less oriented towards marketing or organizational innovation), which is not the case in Germany. Yet Germany seems to be slightly more oriented to eco-product innovations since the improvement in the product quality (*prodquality*) and the market orientation (*market*) play a significant important role in this country. In Germany, the results also support the existence of significant 'product innovation offsets' in the sense of Porter and van der Linde (1995).

The geographic market orientation does not seem to be a specific characteristic of eco-innovations compared to other innovations, whereas eco-innovations seem to be more often realized by bigger firms – a result shown by the significant and positive coefficient of *size* in France and Germany.

Concerning knowledge bases and sources of information, the results are quite interesting since they bring empirical support to the hypothesis (H3) according to which eco-innovative activities require more external sources of knowledge and information than innovation in general. For France, universities, consultants and conferences as information sources are very important for eco-innovators. This may be explained by the fact that eco-innovations are often characterised by relatively new technologies, such as renewable energies, where more basic research is needed and - because of its public good character - has to be realised by public research institutions. In Germany, a similar picture can only be observed using a model without the health and safety impacts (see Appendix 2). In this model, state dependent research institutes (*publicinfo*) are an important information source for eco-innovations compared to other innovations.

Concerning internal sources of information, the results are much contrasted between both countries. In France, it seems that, even though eco-innovative activities rely more on external sources of information, internal sources remain very important. For the French sample, we can conclude that eco-innovations tend to be globally (whatever the sources) more knowledge and information intensive than innovation in general. But in Germany, the results suggest that eco-innovations use more external information, particularly coming from public sources, and less internal information than innovation in general. This difference between France and Germany may be explained by the fact that the French sample is more oriented towards process innovations requiring more internal knowledge and cooperation between the different departments of a firm. But this explanation remains partial since supplementary qualitative data would be necessary in order to go deeper in the analysis of the sources and role of knowledge in eco-innovative activities.

## Table 3: Determinants of environmental innovations compared to other innovations in the French and German industry

Dependent variable: Ecoinnovation:
1 High or medium reduced environmental or health and safety impacts
0 Other innovations

Correlates

| | France | Germany | | France | Germany |
|---|---|---|---|---|---|
| *Policy measures* | | | *Barriers* | | |
| Regulation | 0.54 (25.9)$^{***}$ | 0.31 (10.3)$^{***}$ | BarrierCosts | 0.01 (0.36) | -0.05 (-1.54) |
| Subsidies | -0.01 (-0.34) | -0.00 (-0.04) | Barrierknow | 0.04 (1.85)$^{*}$ | 0.04 (1.21) |
| *Market pull* | | | *Information sources* | | |
| Market | 0.04 (1.23) | 0.06 (1.77)$^{*}$ | | | |
| ProdQuality | 0.03 (1.00) | 0.20 (5.26)$^{***}$ | InternInfo | 0.08 (2.31)$^{**}$ | -0.11 (-2.48)$^{***}$ |
| Flexibility | 0.10 (4.17)$^{***}$ | 0.06 (1.95)$^{**}$ | SupplierInfo | 0.03 (1.15) | 0.02 (0.67) |
| MatEnergySav. | 0.30 (13.3)$^{***}$ | 0.26 (8.57)$^{***}$ | ClientInfo | -0.02 (-0.92) | -0.08 (-2.00)$^{**}$ |
| | | | CompetitorInfo | -0.04 (-1.55) | 0.01 (0.44) |
| *Market characteristics* | | | ConsultInfo | 0.06 (1.91)$^{*}$ | 0.02 (0.50) |
| | | | Universities | 0.10 (2.92)$^{***}$ | 0.02 (0.52) |
| | | | Publicinfo | 0.03 (0.68) | 0.04 (0.93) |
| Size | 0.00 (4.17)$^{***}$ | 0.00 (2.00)$^{**}$ | Infoconference | 0.04 (1.84)$^{*}$ | -0.03 (-0.84) |
| LocalMarket | 0.02 (0.88) | 0.02 (0.67) | | | |
| NatMarket | -0.01 (-0.27) | -0.05 (-1.20) | | | |
| EurMarket | 0.03 (0.87) | -0.01 (-0.34) | *Appropriability* | | |
| OtherMarket | -0.04 (-1.30) | -0.04 (-1.09) | | | |
| Barrierestablish | -0.03 (-1.06) | 0.01 (0.18) | Patent | 0.05 (2.16)$^{**}$ | 0.09 (2.33)$^{**}$ |
| UncertaintyDde | -0.00 (-0.07) | -0.02 (-0.67) | Copyright | -0.03 (-0.88) | -0.04 (-0.93) |
| | | | Secrecy | 0.02 (0.62) | 0.01 (0.36) |
| *Innovative activities* | | | Complexity | -0.02 (-0.74) | -0.03 (-0.77) |
| | | | Timelead | -0.01 (-0.26) | 0.01 (0.35) |
| | | | *Sectoral variables* | | |
| R&D | -0.11 (-3.53)$^{***}$ | -0.01 (-0.13) | | | |
| Product | 0.08 (2.90)$^{***}$ | -0.02 (-0.59) | | | |
| Process | 0.10 (3.70)$^{***}$ | 0.03 (1.23) | | | |
| Marketing | -0.01 (-0.25) | 0.04 (1.31) | HHI | -0.08 (-0.46) | -0.06 (-0.45) |
| InvExtKnow | -0.01 (-0.25) | 0.02 (0.58) | PACE | -0.04 (-0.70) | 0.03 (3.27)$^{***}$ |
| Coop | 0.00 (0.02) | -0.06 (-1.54) | | | |

Probit regressions:
1) France: Number of observations: 3421. $Chi^2 = 1811$. Pseudo $R^2 = 0.38$.
2) Germany: Number of observations: 1464. $Chi^2 = 427$. Pseudo $R^2 = 0.22$.
Z-statistics are given in parentheses. $^{*}$, $^{**}$, $^{***}$ denote significance at the 10%, 5% and 1% level, respectively. Instead of coefficients, marginal effects are reported.

The discussion on the role of internal information can be linked to the role of internal R&D which seems to have a negative effect on eco-innovation. This negative effect is very significant in France which means that, in France, eco-innovative firms are doing less internal R&D than innovative firms in general. This result tends to show that in the case of eco-innovation, firms do not need to invest in internal R&D in order to increase their absorptive capacity of external sources of knowledge. But this result is not significant in Germany.

Finally in spite of the differences between both countries, the results allow us to argue that eco-innovations tend to be more knowledge and information intensive than innovation in general and that internal R&D is not the most important source of innovation. Such a result is important in terms of policy implications since it gives support to the idea that eco-innovations must be supported by innovation policy instruments such as information diffusion policy, technology transfer policy and public-private partnerships in order to help firms to overcome knowledge barriers (which appear to be significant in the French sample).

Another strong similarity between the two countries is the important use of patents to protect eco-innovations supporting our hypothesis H4. In both countries, the results show that eco-innovative firms tend to patent significantly more than general innovators. This result tends to show that the question of private appropriation is essential in eco-innovative activities, which also underscores the strategic dimension of eco-innovation. This feature on patent can be explained by several arguments. First of all, the patent literature tends to show that firms in high technological opportunities sectors and so firms innovating on rather new or emergent technology tend to patent more intensively their innovation than other firms (Peeters and van Pottelsberghe, 2006). Eco-innovation and green technology can be seen as a new challenge for industrial firms opening a lot of new technological and market opportunities which can justify the high propensity to patent. Secondly, the literature on patent also shows that the importance of the development of new products in a firm's innovation strategy is associated with a higher probability to patent and a larger patent portfolio (Brouwer and Kleinknecht, 1999; Peeters and van Pottelsberghe, 2006). Our data suggest that eco-product innovations are very important which contribute to explain the trend towards patenting. Another important argument is the fact that eco-innovators tend to use more external sources of knowledge than other innovators. As emphasized by Peeters and van Pottelsberghe (2006), the firms which are more outward-oriented in R&D and which use more external sources of knowledge and enter into R&D collaboration agreements tend to patent more. As a matter of fact, launching research partnerships is likely to increase the need for patent protection because it implies a sharing of knowledge with external organizations: "a legally enforceable protection mechanism such as patent is helpful to clarify issues of ownership over co-developed knowledge" (Peeters and van Pottelsberghe, 2006, p. 114). Brouwer and Kleinknecht (1999) also show that firms participating in research partnerships and using more external sources of knowledge apply for more patents than firms that focus more on internal R&D. All these arguments contribute to explain why eco-innovative firms tend to patent more than innovative firms in general.

## 4. Summary and policy implications

In both countries, the regulatory push-pull effect seems to be highly relevant for eco-innovations documented by the significance of the respective variables (H1). This result confirms the importance of regulatory instruments in stimulating eco-innovations by industrial firms. Furthermore cost savings, especially material and energy savings play an important role in triggering eco-innovations in both countries (H2). Even if there are differences between both countries, the results tend to corroborate that eco-innovations are carried out with multiple objectives, and more particularly that they are combined with productive efficiency objectives. On this point, the results illustrate empirically the idea that firms can find synergies bet-ween competitiveness objectives and environmental ones through eco-innovations. More specifically, our sample brings support to the existence of significant 'process innovation offsets' in the sense of Porter and van der Linde (1995). In more practical terms, the results underscore that, in industrial sectors, process eco-innovations are conducive to materials and energy savings, decrease in production costs and improvements in flexibility.

In both countries, eco-innovative activities seem to require more external sources of knowledge and information than innovation in general (H4). State dependent research institutes as innovation source are very important whereas other innovations rely more on a high human capital intensity within the firm. This may be explained by the fact that eco-innovations are often characterised by relatively new technologies, such as renewable energies, where more basic research is needed and - because of its public good character - has to be realised by public research institutions. In spite of the differences between both countries, the results enable us to argue that eco-innovations tend to be more knowledge and information intensive than innovation in general and that it is not internal R&D which is the most important source of innovation. Such a result is important in terms of policy implications since it gives support to the idea that eco-innovations must be supported by innovation policy instruments such as information diffusion policy, technology transfer policy and public-private partnerships in order to help firms to overcome knowledge barriers (which appear to be significant in the French sample).

Another strong similarity between the two countries is the important use of patents to solve the appropriation problem of eco-innovations. In the German sample, secrecy also appears to be a preferred mode of protection of eco-innovations (see Appendix 1). Overall, the results tend to show that the question of private appropriation is essential in eco-innovative activities of firms, which also underscores the strategic dimension of eco-innovations.

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# Appendix 1: Definition of variables and descriptive statistics for France and Germany

| Name of variable | Description | France | | Germany | |
|---|---|---|---|---|---|
| | | Mean | Std. Dev | Mean | Std. Dev |
| Ecoinnovation | 1 Environmental innovators: realization of innovations with high or medium environmental effects or impact upon health and safety, 0 Other innovators | 0.52 | 0.50 | 0.40 | 0.49 |
| EnvGermany | 1 Environmental innovators: realization of innovations with high or medium environmental effects, 0 Other innovators | - | - | 0.29 | 0.45 |
| *Policy measures* | | | | | |
| Regulation | Fulfilment of regulation and standards (1 high, medium, 0 other) | 0.59 | 0.49 | 0.31 | 0.47 |
| Subsidies | 1 financial aid from public institutions, 0 no financial aid | 0.26 | 0.44 | 0.28 | 0.45 |
| *Market pull* | | | | | |
| Market | Increase of the market share (1 high, medium, 0 other) | 0.82 | 0.38 | 0.60 | 0.49 |
| ProdQuality | Improvement of product quality (1 high, medium, 0 other) | 0.79 | 0.41 | 0.73 | 0.44 |
| Flexibility | Improvement of production flexibility (1 high, medium, 0 other) | 0.61 | 0.49 | 0.56 | 0.50 |
| MatEnergySav. | Reduction of material or energy cost (1 high, medium, 0 other) | 0.46 | 0.50 | 0.33 | 0.47 |
| *Market characteristics* | | | | | |
| Size | Number of employees 2002 | 396 | 1887 | 1030 | 11306 |
| LocalMarket | Local market (1 yes, 0 no) | 0.69 | 0.46 | 0.37 | 0.48 |
| NatMarket | National market (1 yes, 0 no) | 0.92 | 0.27 | 0.77 | 0.42 |
| EurMarket | European market (1 yes, 0 no) | 0.78 | 0.41 | 0.61 | 0.49 |
| OtherMarket | Other market (1 yes, 0 no) | 0.63 | 0.48 | 0.41 | 0.49 |
| Barrierestablish | Competitive pressure coming from established firms (1 high, medium, 0 other) | 0.40 | 0.49 | 0.28 | 0.45 |
| UncertaintyDde | Level of uncertainty on demand (1 high, medium, 0 other) | 0.47 | 0.47 | 0.33 | 0.47 |
| *Innovative activities* | | | | | |
| R&D | Internal R&D investment (1 yes, 0 no) | 0.83 | 0.38 | 0.73 | 0.44 |
| Product | Product innovation (1 yes, 0 no) | 0.71 | 0.45 | 0.94 | 0.90 |
| Process | Process innovation (1 yes, 0 no) | 0.72 | 0.45 | 0.81 | 0.99 |
| Marketing | Marketing innovations (1 yes, 0 no) | 0.33 | 0.47 | 0.49 | 0.50 |
| InvExtKnow | Investments in external knowledge (1 yes, 0 no) | 0.25 | 0.43 | 0.45 | 0.50 |
| Coop | R&D cooperations from 2002 to 2004 (1 yes, 0 no) | 0.48 | 0.50 | 0.31 | 0.46 |
| *Barriers* | | | | | |
| BarrierCosts | Cost factors (1 high, medium, 0 other) | 0.71 | 0.45 | 0.61 | 0.49 |
| Barrierknow | Lack of knowledge (1 high, medium, 0 other) | 0.57 | 0.50 | 0.25 | 0.43 |
| *Information sources* | | | | | |
| InternInfo | Internal information (1 high, medium, 0 other) | 0.87 | 0.33 | 0.82 | 0.39 |
| SupplierInfo | Supplier information (1 high, medium, 0 other) | 0.53 | 0.50 | 0.57 | 0.50 |

| | | | | | |
|---|---|---|---|---|---|
| ClientInfo | Client information (1 high, medium, 0 other) | 0.61 | 0.49 | 0.72 | 0.45 |
| CompetitorInfo | Competitor information (1 high, medium, 0 other) | 0.38 | 0.49 | 0.47 | 0.50 |
| ConsultInfo | Consultant information (1 high, medium, 0 other) | 0.21 | 0.40 | 0.14 | 0.35 |
| Universities | Information from universities (1 high, medium, 0 other) | 0.16 | 0.36 | 0.27 | 0.44 |
| Publicinfo | Public information (1 high, medium, 0 other) | 0.10 | 0.30 | 0.13 | 0.33 |
| Infoconference | Conferences, fairs, exhibitions as information source (1 high or medium, 0 other) | 0.36 | 0.48 | 0.51 | 0.50 |
| *Appropriability* | | | | | |
| Patent | Registration of a patent (1 yes, 0 no) | 0.45 | 0.50 | 0.40 | 0.49 |
| Copyright | Enforcement of a copyright (1 yes, 0 no) | 0.10 | 0.30 | 0.12 | 0.32 |
| Secrecy | Secrecy of inventions (1 yes, 0 no) | 0.35 | 0.48 | 0.52 | 0.50 |
| Complexity | Complexity of design (1 yes, 0 no) | 0.30 | 0.46 | 0.25 | 0.43 |
| Timelead | Time lead with regard to competitors (1 yes, 0 no) | 0.41 | 0.49 | 0.54 | 0.50 |
| *Sectoral variables* | | | | | |
| HHI | Herfindahl Hirschman Index by sectors | 0.04 | 0.06 | 0.15 | 0.12 |
| PACE | Share of environmentally related investment with respect to total investment in % | 6.02 | 17.01 | 2.17 | 1.90 |

# Appendix 2: Determinants of environmental innovations compared to other innovations: Results for the German model with and without health/safety impacts

*Model 1: Dependent variable 1 "EnvGermany":*
1 High or medium reduced environmental impacts
0 Other innovations

*Model 2: Dependent variable 2 "EcoInnovation":*
1 High or medium reduced environmental or health and safety impacts
0 Other innovations

Correlates

| | Model 1 | Model 2 | | Model 1 | Model 2 |
|---|---|---|---|---|---|
| *Policy measures* | | | *Barriers* | | |
| Regulation | 0.22 (8.02)$^{***}$ | 0.31 (10.3)$^{***}$ | BarrierCosts | -0.03 (-0.94) | -0.05 (-1.54) |
| Subsidies | -0.04 (-1.22) | -0.00 (-0.04) | Barrierknow | 0.03 (1.08) | 0.04 (1.21) |
| *Market pull* | | | *Information sources* | | |
| Market | 0.08 (2.51)$^{***}$ | 0.06 (1.77)$^{*}$ | | | |
| ProdQuality | 0.08 (2.28)$^{**}$ | 0.20 (5.26)$^{***}$ | InternInfo | -0.09 (-2.15)$^{**}$ | -0.11 (-2.48)$^{***}$ |
| Flexibility | 0.07 (2.33)$^{**}$ | 0.06 (1.95)$^{**}$ | SupplierInfo | 0.02 (0.88) | 0.02 (0.67) |
| MatEnergySav. | 0.27 (9.86)$^{***}$ | 0.26 (8.57)$^{***}$ | ClientInfo | -0.01 (-0.24) | -0.08 (-2.00)$^{**}$ |
| | | | CompetitorInfo | 0.03 (1.05) | 0.01 (0.44) |
| *Market characteristics* | | | ConsultInfo | -0.00 (-0.01) | 0.02 (0.50) |
| | | | Universities | -0.01 (-0.35) | 0.02 (0.52) |
| | | | Publicinfo | 0.08 (1.92)$^{**}$ | 0.04 (0.93) |
| Size | 0.00 (2.78)$^{***}$ | 0.00 (2.00)$^{**}$ | Infoconference | -0.04 (-1.65)$^{*}$ | -0.03 (-0.84) |
| LocalMarket | 0.00 (0.14) | 0.02 (0.67) | | | |
| NatMarket | -0.05 (-1.49) | -0.05 (-1.20) | | | |
| EurMarket | 0.00 (0.10) | -0.01 (-0.34) | *Appropriability* | | |
| OtherMarket | -0.02 (-0.57) | -0.04 (-1.09) | | | |
| Barrierestablish | 0.03 (0.87) | 0.01 (0.18) | Patent | 0.07 (2.26)$^{**}$ | 0.09 (2.33)$^{**}$ |
| UncertaintyDde | -0.01 (-0.45) | -0.02 (-0.67) | Copyright | -0.10 (-2.64)$^{***}$ | -0.04 (-0.93) |
| | | | Secrecy | 0.06 (1.69)$^{*}$ | 0.01 (0.36) |
| *Innovative activities* | | | Complexity | 0.01 (0.37) | -0.03 (-0.77) |
| | | | Timelead | -0.04 (-1.08) | 0.01 (0.35) |
| R&D | -0.04 (-1.02) | -0.01 (-0.13) | *Sectoral variables* | | |
| Product | -0.03 (-1.19) | -0.02 (-0.59) | | | |
| Process | 0.04 (1.69)$^{*}$ | 0.03 (1.23) | | | |
| Marketing | 0.03 (1.15) | 0.04 (1.31) | HHI | -0.09 (-0.80) | -0.06 (-0.45) |
| InvExtKnow | 0.02 (0.81) | 0.02 (0.58) | PACE | 0.02 (3.48)$^{***}$ | 0.03 (3.27)$^{***}$ |
| Coop | 0.01 (0.32) | -0.06 (-1.54) | | | |

Probit regressions:
Model 1: Number of observations: 1463. $Chi^2 = 385$. Pseudo $R^2 = 0.22$.
Model 2: Number of observations: 1464. $Chi^2 = 427$. Pseudo $R^2 = 0.22$.
Z-statistics are given in parentheses. $^{*}$, $^{**}$, $^{***}$ denote significance at the 10%, 5% and 1% level, respectively. Instead of coefficients, marginal effects are reported.

In Section 3, we estimated the common model for France and Germany including health and safety impacts to establish comparability between the two countries. The German questionnaire allows separating health/safety and environmental effects so that we also estimated a model regarding the mere environmental effects for this country. In fact, the results of the two models do not differ substantially (see Appendix 2). The differences can be summarized as follows:

- The marginal effect for product quality as innovation effect is higher when including health and safety aspects – indeed not a surprising result;
- Information from clients (ClientInfo) are not significant for other innovations within the model with mere environmental effects;
- Public research institutions are significantly important for eco-innovations in the model without health/safety impacts supporting our theoretical considerations (see also Section 2 and 3);
- Concerning the appropriation of innovations, copyrights seem to be significantly more important for other innovations regarding the model with mere environmental effects whereas secrecy seems to be more relevant for environmental innovations.

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