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The Determinants of Environmental Innovations and Patenting: Germany Reconsidered

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Abstract

This paper provides new evidence on the objectives and determinants of different types of innovations and patents, environmental as opposed to other innovations and patents, and different variants of environmental innovations and patents. We investigate how firm-specific and sector-specific driving forces differ by innovation type. Moreover, we outline the functions that different innovation types have for environmental and innovation policies. We find that eco-innovators put relatively more attention to cost reduction, in particular the reduction of energy and resource costs, compared to other innovators. Cost pressure and reliable, predictable and strict framework conditions of environmental policy turns out to be an important driver for more incremental, firm-level eco-innovations contributing to the diffusion of principally known technologies among firms. By contrast, more far-reaching patented eco-innovations are driven by the opportunity to create new markets and by government subsidies.

JEL Code: Q55, O33, O38, C25.
Keywords: Environmental innovation, patent, discrete choice models.

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1. Introduction

Environmental (or eco-) innovations are widely considered a key factor for achieving higher environmental performance of firms and the environmental sustainability of the economy as a whole. Environmental innovations are likely to reduce pollution or the negative impacts of resource use. Thereby, they influence the direction and quality of (technological) progress. At the same time, it is widely believed that environmental innovations allow firms to comply with environmental goals or regulations in a cost effective way.

Policy makers that think about implementing environmental regulations and incentives aim to internalise negative environmental externalities. Yet, they also want to provide favourable conditions for firms in order to ensure or even promote their competitiveness. Hence, the effects of environmental policies have to be considered in a wider perspective, making it necessary to understand the key driving factors for innovations and eco-innovations in particular.

Yet, relatively little is known about the key driving factors of a range of environmental innovations, and their differences to other, general innovations. Using the share of firms that has implemented a product or process innovation as an indicator for innovativeness fails to uncover the wide variation in innovation activities and capabilities across firms and sectors. Some firms may be at the cutting edge of their market, developing products and technologies that are truly novel. Other firms may invest little in in-house development activities and instead adopt new technology from others (with subsequent internal adjustments in the production process, firm organization etc.). At the same token, an increase or decrease in such a simple indicator does not necessarily mean that innovation support policies have failed or succeeded - a net increase could be due to a decline in the share of firms with highly developed capabilities combined with an increase in minimally innovative firms. Moreover, an environmental innovation that helps firms to reduce the cost of regulation may be quite different from another environmental innovation that serves to enter into new markets or increase market share in existing markets.

Another frequent problem in the literature on eco-innovations is that results are not comparable across studies due to different measurement approaches. Often surveys are used to build innovation output indicators and to explore the determinants, obstacles or impacts of innovations. While surveys are flexible and fairly easy to implement, they typically also have shortcomings. In particular, it is difficult to control for subjective influences and strategic behaviour or ignorance on behalf of the respondents, to ensure high response rates and to judge the reliability of the reported data. Also, there may be a self-selection bias in surveys both in the composition of the survey population and survey response. Another innovation indicator are patents. A patent assigns the right to the inventor to exclude others from the unauthorized use of the disclosed invention for a predetermined period of time. For a patent to be granted, the invention must be novel, non-trivial, and useful (i.e. economically valuable). As opposed to survey information patents are more objective and reliable innovation indicators and do not suffer from response bias and low response rates. Also, using patents allows to focus on the narrower subset of more radical and costly innovations and to exclude incremental innovations which are not worth to be patented. Yet, patents primarily measure inventions (i.e. inputs) and not marketed innovations and do not capture some important innovation activities (e.g. many process or organizational innovations).

This paper provides new evidence on the determinants and objectives of different types of innovations and patents, environmental as opposed to other innovations and patents and different variants of environmental innovations and patents. We investigate how firm-specific and sector-specific driving forces differ by innovation type. Moreover, we outline the functions that different innovation types have for environmental and innovation policies. For this purpose we employ a large-scale survey that is representative of the German manufacturing industries and primarily uses the firm database Amadeus. The survey was undertaken in late 2007 and repeated in late 2009 to account for changes in time in the spirit of Horbach (2008). Building on Wagner (2007) we also employ patent data in addition to survey data, using patents as a proxy for innovation. The datasets are combined consistently and allow a thorough analysis of innovation and eco-innovation choices.

The remainder of the paper is organized as follows. In section 2 we briefly review the empirical literature. A short conceptual and theoretical background is provided in section 3 in order to derive basic hypotheses. In section 4 the data and the variables are presented along with descriptive statistics. Section 5 introduces the econometric models used and presents the results for the various regressions. We conclude in section 6.

2. Selected previous empirical evidence

Empirical analyses of the determinants of environmental innovations have been carried out at least since the late 1990s. While earlier studies suffer from data limitations and poor indicators for environmental innovations or environmental policy more recent studies alleviate some of these shortcomings. We summarize the results of prior work most relevant for our empirical study including a discussion about measurement issues, empirical methodology and research gaps.

Jaffe and Palmer (1997) capture innovation in terms of both R&D expenditures and patents in a panel data framework for the US manufacturing industry in the period 1977 to 1989. They find that higher lagged abatement costs lead to an increase of R&D expenditures but they do not support the hypothesis that the number of patents increased in response to environmental regulation. This may be due to the fact that they use all R&D and patents, whether environmental related or not. Also, private pollution abatement expenditures as proxies for regulatory stringency may not be truly exogenous. Brunnermeier and Cohen (2003) use a panel data set for the US manufacturing industry during the period 1983 through 1992 analyzing empirically factors that determine environmental technological innovation focusing on environmental patents only. They find that environmental innovation as measured by the number of successful environmental patent application granted to the industry responded to increases in pollution abatement expenditures, but only marginally. By contrast, increased monitoring and enforcement activities did not turn out to affect eco-innovation activities.

Existing studies using solely patents as a dependent variable are usually not based on firm-level but on aggregated industry-level data. Moreover, they are biased towards product innovation and exclude many other types of innovation, most notably process innovations. Survey based studies allow to distinguish between many different types of innovations and can also include many different firm- and sector-level determinants and control variables for more detailed analyses.

Most survey based studies find that strict environmental regulations affect environmental process innovation (Cleff and Rennings, 1999; Johnstone et al., 2007). The effect of regulation on product innovations is more ambiguous which may be due to different specifications of what constitutes a regulation. Cleff and Rennings (1999) indicate that "soft" regulatory instruments (eco-audits, voluntary commitments, eco-labels) along with market pressures are important for product innovators enabling them to use their environmental performance in their marketing strategies or in negotiations with the government. They also suggest that more traditional instruments are more important for the adoption of innovations among more passive firms. Rehfeld et al. (2007) use a company level data set for the German manufacturing sector and subsequent econometric analysis applying binary and multinomial discrete choice models. Environmental policy - measured broadly by the importance given to compliance with existing and future legal requirements as an important innovation goal - is found to have a weekly significant positive effect on environmental product innovation. They also suggest that the environmental policy proxy has a positive effect on the realization of both environmental product and process innovation together instead of only one type of environmental innovation. More specifically, they find that the certification of environmental management systems (ISO 14001, European Management and Audit System) as well as waste disposal measures and product take back systems have a significantly positive effect on environmental product innovations.

Rennings et al. (2006) report in a similar study the positive influence of environmental management systems and its maturity on environmental process innovations and a more indirect effect on environmental product innovations (via EMS based learning processes). They also find that a specialized R&D department facilitates environmental innovations. Finally, Wagner (2008) finds that environmental management systems are associated with process innovations but not product innovations.

Frondel et al. (2007) is one of the few survey based econometric studies that further distinguishes between different types of environmental process innovations: on one hand, cleaner production reducing resource use or pollution at the source by using cleaner products/materials and production methods, on the other hand end of pipe technologies curbing pollution conditions by implementing add-on measures. They first use a multinomial logit model to identify the determinants of end of pipe and cleaner production technology and then employ a binary probit model in order to investigate the impact of these factors on the environmental product and process innovations selected by facility. Estimation results indicate that cost savings, general management systems and specific environmental management tools tend to favour cleaner production and that regulatory measures and the perceived stringency of environmental policy are positively correlated to end of pipe technologies. Therefore, the implementation of cleaner production methods may also be motivated by market forces (which may indirectly be affected by environmental policy measures). Regarding the choice between product and process innovations the determinants are found to be quite similar which is attributed to the fact that product innovations often include process changes "from cradle to grave". They also mention that the choice between end-of-pipe technologies and integrated measures (and possibly between environmental product and process innovations) is restricted due to different technological and market characteristics.[1] This is broadly captured by sector dummies but not elaborated in more detail. Frondel et al. (2007) also indicate that generally policy stringency is more important than the choice of a single policy instrument when the latter can only be measured inaccurately.

Horbach (2008) is one of the few studies using information from two different surveys (namely the Mannheim Innovation Panel (MIP) and the Employment Panel of the Institute for Employment Research (IAB)) and exploiting - for one of the surveys - information from two different points in time. Also, Horbach (2008) is able to distinguish between the innovation determinants of eco-innovators as opposed to other innovators. Using various discrete choice models econometric estimations confirm that the improvement of technological capabilities by R&D and the qualification of employees promotes innovation in general and eco-innovation in particular. Demand factors proxied indirectly by expected turnover or expected employment also drive innovation activities. Environmental management tools and general organizational changes equally stimulate eco-innovations confirming results by Rehfeld et al. (2007) or Frondel et al. (2007). General cost savings trigger eco-innovations but not other innovations according to the 2001 MIP survey. Horbach (2008) suggests that these cost savings are related to the use of environmental management tools reducing information deficits to detect (material and energy) cost saving potentials. The fulfilment of regulations and standards are also a highly important determinant of eco-innovations, but not for other innovations according to the MIP survey. However, it needs to be mentioned that measures with the sole purpose of meeting regulations and standards do not qualify as innovations making inferences difficult (OECD and EUROSTAT, 2005). The evidence seems to be more obvious for subsidies: They

[1] Moreover it may be difficult for firms to clearly attribute their innovation to end-of-pipe technologies or cleaner production.

stimulate environmental product innovations of suppliers of environmental goods and services (compared to suppliers without innovations) according to the IAB panel and they stimulate environmental innovations compared to other innovations according to the MIP survey. Horbach (2008) introduces sector dummies to determine whether certain sectors are more likely to (eco)-innovate. There is weak evidence for the NACE classes 29-37 in the IAB panel and stronger evidence for the chemical industry in the MIP survey. A more elaborate analysis on the sector level based is not carried out, however. It is only mentioned that firms belonging to sectors with high average sales of new products are more likely to innovate.

Studies based on patents and survey based studies have rarely been combined in a common framework. A notable exception to this is Wagner (2007) identifying patented environmental innovations for a data set of firms that responded to a survey on environmental management and innovation in Germany. He suggests that such an approach allows to focus on a narrow set of more radical environmental innovations that are significant enough to be patentable. Moreover, it would also be possible to measure the extent of innovation (e.g. the number of environmental innovations within specific types of innovation) which has not been done in the current literature. Wagner (2007) uses patents, environmental patents and self-reported environmental innovations (but not other innovations) as dependent variables in probit and negative binomial models regressing them against a range of determinants, in particular the level of EMS implementation. He finds that the implementation level of EMS has a weakly positive effect on environmental process innovations, whereas it is negatively associated with the level of the firm's general patenting activities. General and environmental patenting activities are strongly associated with big firms and the implementation of a general quality management system which may be a proxy for overall organizational capabilities. Compared to general patenting environmental patenting is also driven by the cooperation with environmentally concerned stakeholders. The latter is also a driving force for self-reported environmental product innovations, but the evidence is less strong (at the 10% level of significance). Wagner (2007) also includes sector dummies as innovation determinants, but the results differ within the patent equations and between the patent equations and the equation on self- evaluated environmental innovations. This makes it difficult to draw conclusions on this level of analysis. More generally, a limitation of the study is that the data set is fairly small to draw firm and robust conclusions: Only 342 firms answered the survey and only 121 of them have patented in the period 1999-2004 (including 41 firms with environmental patents). The multivariate Probit model for self-evaluated environmental innovation only includes 152 observations and the various patent models only 248 observations.

The majority of empirical studies find the relation between firm size and innovation to be positive. At least this is true when controlling for other factors, like industry, firm age etc. (Becheikh et al., 2006). It is also well known that big firms patent more than small firms (Kleinknecht et al., 2002; Wagner, 2007). Regarding the above-mentioned survey-based studies on environmental innovations the influence of firm size is less clear: a positive influence is found by earlier studies (Cleff and Rennings, 1999; Rehfeld et al., 2007). Horbach (2008) finds a positive association in the MIP survey relative to non-innovating firms but no statistically significant differences between environmental innovators and other innovators. In the IAB panel the effect of firm size is also insignificant when comparing environmental innovators with non-innovators. Frondel et al. (2007) finds an insignificant impact of firm size for end-of-pipe technologies but a slightly positive impact for cleaner production. Baylis et al. (1998) argue that environmental activities go along with a higher amount of financial and human resources which is why larger firms have better opportunities and abilities to reduce environmental impact.

There's also an ambiguous effect of firm age and ownership structure on innovation (Becheikh et al., 2006). In Horbach (2008) firm age is insignificant, Wagner (2007) reports that firm age is weekly positively associated with self-evaluated environmental innovations. No significant difference is found with respect to firm ownership in Wagner (2007).

This short literature review indicates that there are earlier studies that had similar research aims to our study. Yet, our work presents novelties in several respects: Firstly, we combine survey indicators of several types of (eco-)innovations and (eco-)patents in a common framework and analyze eco-innovation determinants in a more comprehensive and thorough manner than previously. Secondly, we report results from two survey periods in a panel data framework. Unlike previously, there are no potential inconsistencies from applying different surveys and survey designs across the various (eco-

)innovation choices being analyzed. Thirdly, differences in eco-innovation activities and its determinants across sectors are studied explicitly. Previous work has not studied sector-effects explicitly by running regressions industry-by-industry.

3. Conceptual background and research hypotheses

This section provides a short overview of the main elements of innovation theory in general and environmental innovations in particular to derive empirically testable hypotheses for the determinants of environmental innovations (see e.g. Jaffe et al., 2002 for a more extensive review). Traditionally, technological progress is explained at the micro-level of the individual market using supply- and demand-side factors. As a result, the technology-push (supply-side) hypothesis is often contrasted to the market-pull (demand-side) hypothesis. The former states that innovations are driven by technological capabilities encompassing the physical and knowledge capital stock of the firm to develop new products and processes. To build up such a capital stock a firm typically needs to make costly and risky investments into R&D and skilled employees and may also need to develop related organizational capabilities. According to the market-pull hypothesis (expected) demand from consumers, other firms or the government are decisive innovation determinants, especially concerning product innovations. The starting hypothesis is therefore that non-innovating firms perceive high costs or lack of demand as a major obstacle to innovations relative to innovating firms (*hypothesis I*).

Following neo-classical economic theory eco-innovations differ from other innovations because they produce a double externality (Rennings, 2000; Jaffe et al., 2002). External benefits arise because the inventor will typically fail to appropriate all or most of the social returns from R&D activities. In addition, prices do often not reflect the true scarcity and the true social costs of all resources providing incentives for innovation to use the under-priced factor input more intensively (induced innovation hypothesis). Therefore, pure market forces emerging in a competitive non-regulated economy might not per se induce resource or pollution saving technological progress, and, even if they do, the right direction of technological progress is not guaranteed (i.e. not necessarily those resources with the highest social shadow prizes are saved in the first place). Beyond the above mentioned technology-push and market-pull factors, the environmental policy framework is therefore an important determinant of eco-innovations. Environmental policy implicitly or explicitly makes environmental inputs more expensive leading to an increase in R&D (and possibly R&D productivity) focused on reducing the use of that factor (induced innovation hypothesis, see Hicks, 1932; Binswanger and Ruttan, 1978). Moreover, according to the contested Porter-hypothesis which is largely based on evolutionary innovation theory firm's eco-innovation activities do not follow a strict optimization process (Porter and van der Linde, 1995; Nelson and Winter, 1982). Therefore, environmental regulation may reorient firms innovative search strategies and make them recognize the previously untapped cost-saving potentials or efficiency gains of many environmental innovations. We hypothesize that eco-innovating firms are more sensitive to cost savings whereas other innovators pursue more often traditional innovation objectives that may only indirectly be related to cost, like the replacement of outdated products or the realization of technological gains (*hypothesis IIa*). Another variant of the Porter-hypothesis states that environmental policy may help generate first-mover advantages vis-à-vis firms from other countries which have not (yet) adopted similar (or similarly strict) regulation. This stimulus provides benefits to sectors that develop environmental technologies (the so-called environmental industry) in helping them to secure market shares or to expand into new markets (*hypothesis IIb*).

The type and significance of environmental innovation activities differ markedly and, accordingly, the role of innovation determinants varies, too. A basic distinction is often made between product and process (eco-)innovations. Process innovations typically improve the efficiency of creating or establishing a product or service. Customer benefits result from reduced prices through cost savings (e.g. appliance with improved energy efficiency) and sometimes improved product quality or durability. Product innovations are new outputs or services that are introduced for the direct benefit of customers with the new product being noticeably different from the older product or service. For environmental product innovations the environmental consciousness of consumers is an important characteristic of demand. According to the strategic management literature firms may also use environmental product innovations as a differentiation tool that helps to maintain or increase market share (Meffert and Kirchgeorg, 1998). Moreover, the broader social pressure may influence firm's activities. We hypothesize that environmental process innovations are primarily undertaken to reduce energy and resource costs whereas environmental product innovations are driven by demand factors, opportunities in environmental markets and social pressure (*hypothesis III*).

Innovation may be new to the firm or new to the market. If the innovation is new to the firm, the innovation was first developed and commercialized elsewhere, but later adopted by other firms and incorporated into their production process in an innovative way. New-to-the-market innovations as well as patented innovations typically require more fundamental and often collaborative R&D activities to be able to compete at the technological frontier and to be first on the market. For environmental policy it is more difficult to directly influence complex innovation processes that lead to market innovations. Policymakers are unable to guarantee the success and to foresee the output of R&D activities and are faced with inherent information asymmetries during the innovation process. By contrast, the diffusion of known eco-innovations (i.e. eco-innovations new to the firm) is easier to accomplish (Rennings et al., 2008). For example, the setting of technical standards and emission limit values and their periodic update provide signals to firms lagging behind in their environmental performance to implement new best available technologies. We may therefore hypothesize that new-to-the-firm innovations are therefore favoured by sufficiently strict and stable environmental policy framework conditions and rising energy and resource costs that are in turn influenced by environmental policy (*hypothesis IVa*). In contrast, new-to-the-market innovations and patents are influenced by technological and market opportunities (technology-push). The influence of policy is more indirect, in particular through research subsidies (*hypothesis IVb*).

The continuity of innovation critically depends on whether continuous incentives to innovate are present. Obviously, it is difficult to generalize whether technology-push or market-pull factors are more important to stimulate continuous innovations. This will depend on sector-specific and product/firm-factors (e.g. the stage in the product lifecycle, export shares etc.). However, firm-specific capabilities and attitudes are crucial to explain innovation success and innovation continuity (van der Panne, 2003). According to the resource-based view of the firm (Wernerfelt, 1984) management practices and organizational activities allow to build valuable strategic resources and competitive advantages which positively influence a firm`s innovative capabilities over time. In this sense, environmental management systems (EMS) have the potential to represent important firm-internal capabilities to facilitate the continuous generation and/or adoption of eco-innovations (Wagner, 2007) (*hypothesis Va*). Apart from these “voluntary” environmental policy measures the continuity of policy-induced incentives is suggested to be realized best through market-based instruments (Jaffe, 2002; Jaffe and Stavins, 2005). Therefore, we hypothesize that the reduction of energy and resource costs (which is strongly influenced by taxes, charges and CO_2-emission permits) is a driving force to continuously generate eco-innovations (*hypothesis Vb*).

In addition, the determinants of innovation differ depending on other firm- and sector-specific factors. Following Schumpeter (1934) there is a positive relationship between market power and firm size on innovation. Schumpeter argues that market concentration reduces market uncertainty and that large firms can realize economies of scale in R&D. However, some argue that market concentration leads to inertia and hinders innovation due to missing competitive pressures (Levin et al., 1985, Geroski, 1990). Therefore, the overall impact of market structure on innovation is ambiguous and may depend on the complexity of innovation or the industry considered. Similarly, the effect of firm age is undetermined: on one hand older firms may have acquired more organizational resources, on the other hand younger firms may be more innovative in order to increase their market share (Ziegler, 2008).
Instead of considering primarily market structure and demand some studies look at specific technological opportunities at the sectoral level. According to evolutionary economics innovations follow distinct technological trajectories, i.e. directions of technical development that are cumulative and self generating. Pavitt (1984) suggested that industrial sectors differ greatly in the sources of technology they adopt, the users of the technology they develop and the methods by successful innovators to appropriate the benefits of their activities. Therefore, we expect different types of (eco-)innovations to be developed by different sectors. More specifically, patents are more frequent for high-quality innovations (Moser, 2007) and patenting as a means to protect the returns of invention are more prevalent in some sectors (e.g. pharmaceutical, mechanical engineering) than in others (e.g. food processing, textile) where secrecy or lead time may help to appropriate the returns of innovations (Cohen, Nelson and Walsh, 2000).

4. Data, variables and descriptive statistics

To analyze different types of (environmental) innovations we primarily use a firm-level data set that is based on a large scale anonymous survey among German firms conducted in late 2007 and repeated in late 2009. The survey includes information on general innovation activities, environmental innovation activities and related innovation objectives, determinants and obstacles. Environmental innovations were defined as a sub-group of general innovations that contribute to an improvement of environmental quality or the use of fewer natural resources[2]. As a result, we can define three distinct types of firms: firms that have not innovated in the period under consideration, firms that have implemented innovations but no innovations with an environmental benefit, and firms which have also carried out at least one environmental innovation. Several questionnaire items allow to further qualify these innovations, for example by their technological orientation (product or process innovation) and the year the innovation was undertaken (2004, 2005 and/or 2006 for the first survey period; 2007, 2008 and/or 2009 for the second survey period). For environmental innovations we can also distinguish whether the innovation is only new to the company or even new to the market. The type of environmental improvement (e.g. reduction of energy consumption, air pollution abatement etc.) is also available. A detailed description of variables is provided in table 1.

Table 1 here

The survey initially targeted 13.469 firms which are drawn from the most comprehensive, pan-European firm database AMADEUS compiled by Bureau van Dijk and based on Verband der Vereine Creditreform as data provider (in case of Germany) (see www.bvdep.com). The database contains important economic and financial data at the firm level and information about firm's sectoral affiliation at the four digit NACE level, its location, ownership structure and date of incorporation. We exclude firms in the service sector focusing instead on the manufacturing industries including electricity, gas

[2] Additionally, the following two sentences are added: “This includes the advancement of existing or the development and market introduction of new environmentally-friendly products or environmental improvements through the modification or replacement of existing processes (add-on or integrated technologies). Environmental improvements may not be directly intended, i.e. they may only be a side-effect of the innovation.”

and water supply and construction. Firms with less than 50 million € operating revenue or less than 20 employees are not included. We also drop some additional firms with pure service or administrative functions. Often they belong to a firm with an active operating business that is still in the data set. Finally, since small firms are somewhat underrepresented in AMADEUS, we add a total of 612 to the 12.857 AMADEUS firms from the regular innovation survey of the ifo Institute for Economic Research. Apart from that, there is no pre-selection of firms and no pre-selection based on firm´s innovation behaviour or environmental management activities.

The survey was pretested to avoid ambiguity and leading questions and to improve scale items as well as question order. Therefore, measurement error is hopefully limited to a minimum.

Of these 13.463 firms, 271 could not be reached, 11.626 refused to participate, and 1572 participated in the first survey. The response rate of 12% is fairly typical for a written study given that such a broad survey of this kind has not previously been undertaken in Germany. However, most questionnaires were filled in completely. An exception is the question on innovation obstacles which was only answered by about 74% of the firms (as some did not consider it to be relevant). Also, employment figures are only available for 84% of the firms and even more often missing across time.

To account for non-response bias we test whether late respondents who received a reminder to answer the survey differ in their innovation behaviour and innovation determinants compared to early respondents (similar to Wagner, 2007). We find a slightly lower share of eco-innovators (-10%) among late respondents and a higher share of non-innovators (+10%). Yet, there are no significant differences in the mean values of innovation determinants and only slight changes in the ranking of these determinants among the two response groups. At any rate, we are left with a considerable share of non-innovators (30%) and "general" innovators (25%) relative to eco-innovators (45%) in the survey response.

Table 2 illustrates the share of different firm sizes (by number of employees) and the share of different industry sectors both for the total sample and the survey response. As can be seen no major differences between the responding firms and the total sample occur. Small firms respond somewhat more often. Yet, they are still underrepresented compared to the official statistics where firms with less than 100 employees represent almost 70% of all firms in manufacturing whereas big firms with more than 500 employees account for only 5% (Statistisches Bundesamt, 2007). This is a common issue in firm surveys, but the potential bias is at least smaller compared to most corporate governance studies given the substantial share of small firms. Regarding industry sectors, the survey respondents also resemble the total sample. However, some sectors are clearly under- or over-represented. For example, there are fewer respondents in food and tobacco, publishing and printing and construction. These sectors are also under-represented when compared to the share of companies in the total number of companies in manufacturing in official statistics. This is likely to result from the large share of small firms in these sectors. By contrast, chemical products and non-metallic mineral products are somewhat over-represented in the survey response. Therefore, firm size and industry sectors variables are needed to account for bias due to size and/or different innovation propensities of industry sectors.

Table 2 here

The same type of survey was repeated in 2009 for the period 2007 to 2009. While this paper mainly analyses the results of the first wave of the survey (given that patent data are only available until 2007, see below), we also considered changes in innovation behaviour across time periods. 627 firms responded twice to our survey. We find that most of those firms do not change their innovation behaviour: 78.3% (76.6%) of the firms (eco-)innovating in the period 2004 to 2006 (eco-)innovate also in the period 2007 to 2009. 11.3% (11.4%) become (eco-)innovators and 10.4% (12.0%) become non-(eco-)innovators. Due to this general picture our main analysis is on aggregate effects that may not have changed over time.

Survey information was complemented by subsequent collection of patent data. We use the World Patent Statistics Database (PATSTAT, version 2007), recently constructed by the European Patent Office and the Organisation for Economic Cooperation and Development (OECD)[3]. PATSTAT is unique in that it covers more than 80 patent offices and contains over 60 million patent documents. PATSTAT includes i.a. information on the title and abstract of an application, the filing and publication dates of an application, the names and origin of the inventors and applicants, and the

3 See http://www.epo.org/patents/patent-information/raw-data/test/product-14-24.html

technological domain of an application according to the international patent classification (IPC). For the firms that were contacted by our survey we merge potential patents using semi-automatic string matching based on firm/applicant names. Matching is based on PERL and the output is carefully screened to ensure correct name attribution. We find that 45% of the 13.463 firms have at least one patent. Then, we extract application and publication information, IPC class and the patent abstract for those firms answering the survey. 72.045 patents are found with 43% of the answering firms having at least one patent.[4] Subsequently, we single out patents potentially being environmentally beneficial based on key word search in the patent abstracts. We use about 300 key words related to environmental quality, resource use and specific technologies using environmental dictionaries to guide the search[5]. Only about every third word occurs in the patent abstracts. 8% of all these patents turn out to be potential eco-patents. Finally, we read the abstract of those remaining patents to have a subset of probable eco-patents. This procedure does not amount to a detailed ecological impact analysis which would be desirable but is clearly beyond the scope of this project. However, a closer look at individual patent abstracts improves upon previous studies which have not tested the validity of key words or assume that all patents belonging to particular IPC classes are environmental patents. It allows to understand the key words in context and to better handle patents containing frequent but imprecise or ambiguous key words. For example, emissions are not only associated with pollution but also with lightning and optics. Table 3 lists the most important key words both before reading the abstract and after it (i.e. among the likely eco-patents). In addition, using such a procedure we are able to further classify eco-patents according to the type of environmental improvement. As a result, we are left with 2.813 eco-patents (about 4% of all patents). They belong to 162 firms.

Table 3 here

As our survey focuses on the years 2004-2006 we restrict our patent sample to patents applied for between 2003 and 2006. Therefore, we end up with 506 firms owning 23.039 patents or 71 firms

[4] Some patents are left out, because they do not contain a patent abstract. This is particularly true for older patents.

5 See e.g. www.umweltlexikon-online.de.

owning 663 eco-patents in our sample. As previously observed, there are a few firms holding many patents and many firms holding only a few. For each firm we build a patent stock based on the number of granted patents in the years 2004 to 2006, whereby earlier patents are multiplied with a yearly discount rate of 15% (Hall, 1990).

Both for patents and self-reported innovations the most important results are also analyzed on the sector level. Four sectors or sector-groups are considered which have each a sufficient number of (eco-)innovations and (eco-)patents and are distinct regarding their function in the economy: mechanical engineering (NACE 29) which is a major backbone of the German economy; electrical and optical equipment (NACE 31-33); primary industry sectors (NACE 23-28) which mostly act as suppliers to other manufacturing industries; and all other manufacturing sectors.

5. Models and results

To test the hypotheses derived in section 2 separate econometric models are employed for self-reported innovations and patents as dependent variables. For both we also build a number of subgroups (various types of eco-innovation and eco-patents) and analyze sector- and time-specific effects to extend on previous research. These additional effects are obtained by multiplying a time dummy or sector dummy with all the independent variables. For self-reported innovations binomial and ordered probit models are used, whereas for patents negative binomial models are applied. Our unbalanced panel data models for self-reported (eco-)innovations (models 1b-6b) are based on random effects panel models that assume that the individual firm effects are uncorrelated with the explanatory variables. Fixed effects panel models were also tested, but the number of observations drops significantly. This is most likely due to the fact that innovation behaviour is only changing slowly across time leaving us too few observations for this type of econometric analysis.

Model 1a and 1b provide some basic insights on why firms innovate and patent or refrain from it. As explanatory variables we refer to firm size and the innovation obstacles that all surveyed firms (i.e. innovators and non-innovators) were asked to answer (see table 4). In both the innovation and the patent regressions firm size is positively associated with innovation activities which is in line with most previous studies. For self-reported innovations two main obstacles explain why some firms choose not to innovate: Compared to innovating firms non-innovators perceive a lack of customer demand and report more organizational rigidities within the firm and lack of suitable partners. Lack of demand also remains a significant obstacle when focusing on the unbalanced panel (model 1b) in addition to the simple probit model. For all the other obstacles there is no significant difference vis-a-vis innovating firms, i.e. the latter also mention obstacles despite the fact that they succeeded to generate innovations. For patents the only significant difference between patenting and non-patenting firms (at the 10% level of significance) is that the latter consider high costs as a more pressing innovation obstacle. This is understandable given the substantial cost of patenting. Overall, results of these first two models are in line with previous findings and in accordance with hypothesis I that non-innovating firms perceive high costs or lack of demand as a major obstacle to innovations relative to innovating firms.[6]

Table 4 here

Models 2a-c aim to find out whether differences in innovation objectives exist between general (non-eco-)innovators and eco-innovators both with respect to their self-reported innovations and their patents. In the survey a question on innovation objectives had to be answered by all innovating firms for their entire innovation activities (environmental and other innovations) (see table 5). Relative to self-reported other innovations environmental innovations are more often pursued to reduce production costs as postulated in hypothesis IIa (similar to Horbach, 2008). However, this is not true for the electrical and optical equipment sectors where environmental innovations are relatively more often pursued to secure market shares or to create new markets. Since the electrical and optical equipment sectors contain an over-proportionate share of eco-innovators we suggest in view of hypothesis IIb that these sectors benefit from first mover benefits (Porter effects) vis-à-vis other countries that take a less active role towards their environmental industry than Germany. In addition, environmental innovations are positively associated with firm size and the existence of an EMS. Firm

[6] We also tested whether there are any differences with respect to these obstacles for eco-innovating firms, but did not find any significant differences.

age is generally not significant, but in the primary industry sectors (like chemicals) younger firms drive the eco-innovation activities (see annex 1).

Table 5 here

The importance of cost reduction is also confirmed when using the random effects panel model for both survey periods (model 2b). In addition, the realization of technological leads is more often pursued by environmental innovators relative to other innovators. However, in the period 2007 to 2009 the reduction of costs has become less important for environmental innovators than in the first survey period (additional time effect).

Looking at the patent regression (model 2c) demonstrates that the value of the patent stock is positively influenced by firm size and higher for younger firms (start-ups). Patenting among innovators is not primarily carried out to reduce costs but to achieve technological leads and to introduce new products as a replacement for outdated products. The difference between firms with general patents only and firms holding also eco-patents can be detected by examining additional effects for the latter group of firms.[7] Interestingly, for eco-patenting firms there are opposing signs: cost reduction does play a certain role (with the effect not being significant), but technology and the creation of new products does not in relative terms.

In annex 1 additional sector-specific effects are examined. In contrast to the general picture the creation of new products is not important for mechanical engineering firms in relative terms, for example. The main objective of these firms is – due to their eco-patenting activities – to serve current markets and to create new markets.

Models 3-7 focus in particular on firms which have undertaken eco-innovation activities between 2004 and 2006 and use a range of determinants which may have influenced these activities as independent variables (see tables 6, 7 and annex 2). Model 3a looks at the continuity of eco-innovations distinguishing between firms innovating only in one year, in two years or in all three years in the period under consideration. We find that environmental management systems (EMS) lead to

[7] The combined effect is broadly captured by subtracting the above variables (objective xy) from the latter variables (objective xy – additional effect).

continuous eco-innovation activities which is in line with hypothesis Va and the philosophy of environmental management systems of delivering continuous environmental improvements in firm operations. Unsurprisingly, large firms and older firms are more capable of creating continuous eco-innovations. Among the direct eco-innovation determinants that were included in the questionnaire the reduction of energy and resource cost is the most important driver of eco-innovation continuity across all sectors. Yet, similar to model 2a for the electrical and optical equipment sectors cost reduction is less important than the continuous creation of new market opportunities. Interestingly, direct and indirect support measures have generally a negative influence. We suspect that subsidies are frequently directed at one-off innovations without providing a continuous stimulus for environmental improvements.

Table 6 here

When looking at the panel data model (model 3b) we can confirm that the reduction of energy and resource costs drives the continuity of eco-innovations.[8] Firms that want to expand into new markets are also more likely (at the 10% level of significance) to eco-innovate continuously as they may be threatened in their competitive position in their current markets. Finally, firm growth is positively associated with the continuity of eco-innovations.

Table 7 here

Model 4a and b make a distinction between eco-innovations that are only new to the firm and eco-innovations that are also new to the market. We find that the latter and more far-reaching innovations are relatively more stimulated by major technological advancements, network activities and new markets (the latter two at the 10% level of significance). This confirms hypothesis IVb stating that new-to-the-market innovations and patents are influenced by technological and market opportunities. Network activities include co-operation with universities and are, almost by definition, intended to

[8] In the second survey period we did not ask whether firms have adopted an environmental management systems so we cannot single out its influence in the panel data model.

result in major innovations. In the extended random effects panel model (model 4b) the importance of technology and new markets can be confirmed. By contrast, more incremental firm-level innovations are driven by conducive environmental policy framework conditions and "voluntary" policy measures like environmental management systems, at least relative to new market innovations. As stipulated in hypothesis IVa, environment policy has an important role to play in the diffusion of principally known eco-innovations, whereas its impact on new eco-innovation is only indirect. Interestingly, this does not hold for the mechanical engineering sector: The environmental policy framework conditions are an important stimulus for new eco-innovations here. In addition, the reduction of energy and resource costs (which are heavily influenced by environmental taxation) drives firm-level eco-innovations relative to market eco-innovations across all sectors. Yet, this effect is no longer significant in model 4b.

Model 5a and 5b distinguish between environmental product and environmental process innovations and consider the determinants of the ecologically most significant innovation which is either a product or process innovation. Vis-à-vis process eco-innovations product eco-innovations are significantly influenced in both models by the opportunity to maintain and enlarge current markets and to create new markets. By contrast, environmental process innovations are mainly realized to reduce energy and resource costs. These results give support to hypothesis III according to which environmental process innovations are primarily undertaken to reduce energy and resource costs whereas environmental product innovations are driven by demand factors and market opportunities. However, customer demand and social pressure turn out to be insignificant for product innovations. Environmental management systems are negatively (positively) associated with product (process) eco-innovations, but in contrast to Wagner (2007) the coefficient is insignificant. Favourable environmental policy framework conditions tend to be more important for process innovations, but the coefficient is also insignificant. Again, there is an opposing and significant positive sign for the mechanical engineering sector. Obviously, many of the renewable energy technologies developed by this sector depend on the supporting role of environmental policy.

Model 6a and b are ordered probit model focusing on the type of environmental improvement of the most important eco-innovation. Since many self-reported eco-innovations serve to reduce energy consumption and CO_2-emissions, we take a closer look at eco-innovations with large and modest energy efficiency potential (relative to eco-innovations which do not contribute to energy efficiency). Interestingly, we find that energy-related eco-innovations are more heavily influenced by subsidies. This result is obviously a consequence of the numerous support measures taken to promote renewable energy and energy efficiency in Germany (e.g. the Renewable Energy Act or the so-called Market Stimulus Program). Yet, many of these innovations are not purely regulation-driven, since the reduction of energy costs and market motives are equally important stimuli for energy eco-innovations (albeit not for the "other sectors"). Both are only modestly correlated with subsidies (correlation coefficients of 0.13 and 0.18, respectively). An interesting finding in model 6b is that the realization of technological leads has also become significantly more important for energy eco-innovators over time (additional time effect). This indicates that newer energy eco-innovations tend to be high-technology products which are frequently exported into other countries. The influence of social pressure on energy innovations seems to be sector-specific: It matters for "other sectors", but is not useful for the primary industry sectors where only market motives and customer demand influence innovation activities in the energy field.

The results on self-reported eco-innovations are contrasted in model 7 with eco-patent stock as dependent variable. Thus, we focus on all firms which have reported eco-innovation activities between 2004 and 2006 with a subset of firms also holding eco-patents. Using the same determinants as in the models before we find that eco-patenting is mainly influenced by the opportunity to create new markets and by government subsidies. The first determinant confirms the results in model 5a and b which have shown that environmental product innovations are stimulated by market demand. The fact that only new market opportunities (and not the service of current markets) are significant for eco-patents suggests that competitive pressures are higher for patented innovations relative to non-patented product innovations. For the more radical patented eco-innovations government support seems to be an additional stimulus. Similar to the previous patent regressions firm size is again positively associated with eco-patenting. These results confirm hypothesis IVb that patents are influenced by technological and market opportunities.

Based on these results for all eco-patents we also tried to separate eco-patents by the type of environmental improvement. Similar to model 6a and b we isolated eco-patents that are likely to reduce energy consumption or enhance energy efficiency. Relative to the entire eco-patent stock value as well as the stock of non-energy-related eco-patents we find that new market is still significant whereas government subsidies are not. This suggests that energy-related subsidies are more useful to firms adopting energy eco-innovations principally developed elsewhere. Surprisingly, the reduction of energy and resource costs turns out to be positive and significant, i.e. the lower their importance the more energy-related eco-patents. A partial explanation might be that those firms that patent develop new products for their customers with only the latter being constrained by energy costs. However it seems that the results on energy patents are generally less robust given the small share of firms with energy patents.

6. Conclusions

Environmental innovations comprise a broad set of activities that are novel to a firm or user and result in the reduction of pollution and the negative impacts of resource use compared to relevant alternatives. From a policy point of view the function of eco-innovations may be manifold: They may allow a cost-effective response of firms to policy goals. This is true for environmental policy which is mainly concerned with the internalization of negative environmental externalities and for research and innovation policy which mainly aims to create favourable conditions for competitiveness and sustainable economic growth. At the same time, policymakers do not define policy goals in a vacuum, but rely on information about which response from the market and which impacts of various innovations can realistically be achieved.

This paper investigates the objectives and determinants of eco-innovations shedding light on the diversity of eco-innovations and the relative importance of innovation drivers for different types of general and eco-innovations. For this purpose we use a firm-level survey undertaken in 2007 and repeated in 2009 as well as corresponding patent data at the firm-level. Based on discrete choice and negative binomial models we test several hypotheses derived from (eco-)innovation research.

The econometric estimations reveal that eco-innovators put relatively more attention to cost reduction, in particular the reduction of energy and resource costs, compared to other innovators. Put differently, higher energy prices prevent firms from excessively using the traditionally underpriced input factor energy. Cost pressure turns out to be an important driver for more incremental, firm-level eco-innovations contributing to the diffusion of principally known technologies among firms. Moreover, high energy costs provide dynamic incentives to generate eco-innovations continuously. At the same time, environmental policy has an important role to play for the diffusion of firm-level eco-innovations: Reliable, predictable and strict framework conditions are equally an important prerequisite for many firms to adopt more incremental and small-scale environmental innovations. Environmental taxes with slowly but steadily rising tax rates may provide the necessary incentives.

However, cost reduction is not the primary objective of firms generating more far-reaching patented innovations. New (patented) innovations are driven by the opportunity to achieve technical leads and introduce new products. Policy contributes to create the necessary framework conditions for the improvement of technological capabilities and the generation of technological novelties. Moreover, it may help firms open-up foreign markets and export new technologies. This active role of policy in providing access to foreign markets seems to be particularly important for patented eco-innovations: On one hand firms with eco-patents seem to face relatively stronger competitive pressures compared to firms with only other patents, on the other hand new environmental technologies may contribute to reduce environmental burdens abroad. The additional policy stimulus for eco-patents may also be given via subsidies. However, subsidies are by nature selective and may narrow down the number of promising technological options to continuously improve environmental performance. Therefore, they need to be properly targeted and designed on a case-by-case basis.

Finally, it is important to note for policy that firm-specific factors (especially firm size) and sector-specific factors co- determine the type of eco-innovation generated by the market. For example, eco-innovations in mechanical engineering directly benefit from environmental support programs for renewable energies. Policy changes may therefore affect industry sectors unevenly and have wider ramifications across the economy.

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Table 1: Description and descriptive statistics of the variables

Name of variable	**Description**	**Obs. (No. of firms)**	**Mean**	**S.D.**
Dependent variables				
Innovation	1 = Innovations undertaken in 2004, 2005 and/or 2006 0 = no innovations undertaken	1552	0.704	0.457
Innovation – both surveys	0 = Innovations undertaken in time period of the surveys 1 = Innovations undertaken in time period of the surveys	3139 (2512)	0.690	0.461
Patentvalue	Value of firm`s patent stock for patents applied for between 2003 and 2006 (incl. firms with no patents)	1552	8.467	72.847
Eco-innovation	0 = other innovations undertaken in 2004, 2005 and/or 2006 1 = Environmental innovations undertaken in 2004, 2005 and/or 2006	1093	0.647	0.478
Eco-innovation – both surveys	0 = Other innovations undertaken in time period of the surveys 1 = Eco-innovations undertaken in time period of the surveys	2033 (1676)	0.664	0.472
Number of eco-innovations	Number of environmental innovations in the years 2004, 2005 and/or 2006	682	1.969	0.901
Number of eco-innovations – both surveys	Number of environmental innovations in the 1st or 2nd survey period	1391 (709)	0.363	0.481
Ecopatentvalue	Value of firm patent stock for patents applied for between 2003 and 2006 (incl. firms with no patents and divided into eco- and other patents)	3.104 (1552)	4.234	50.273
Process eco-innovation	0 = Product eco-innovation (1st survey period) 1 = Process eco-innovation (1st survey period)	579	0.591	0.492
Process eco-innovation – both surveys	0 = Product eco-innovation in the 1st or 2nd survey period 1 = Process eco-innovation in the 1st or 2nd survey period	1166 (572)	0.578	0.495
New-to-market eco-innovation	1 = Eco-innovation only new to the company (1st survey period) 2 = Eco-innovation new to the market (1st survey period)	657	0.511	0.500
New-to-market eco-innovation – both surveys	1 = Eco-innovation only new to the company in the 1st or 2nd survey period 2 = Eco-innovation new to the market in the 1st or 2nd survey period	1360 (694)	0.465	0.499
Energy eco-innovation	0 = eco-innovation with no reduction of energy consumption (1st survey period) 1 = eco-innovation with modest reduct. of energy consumpt. (1st survey period) 2 = eco-innovation with strong reduct. of energy consumpt. (1st survey period)	707	0.833	0.751
Energy eco-innovation – both surveys	0 = eco-innovation with no reduction of energy consumption in the 1st or 2nd survey period 1 = eco-innovation with modest reduct. of energy consumpt. in the 1st or 2nd survey period 2 = eco-innovation with strong reduct. of energy consumpt in the 1st or 2nd survey period	1419 (704)	0.688	0.464
Value of eco-patent stock	Value of firm`s eco-patent stock for patents applied for between 2003 and 2006 (incl. firms with no patents)	3.104 (1552)	0.232	69.129

Independent variables (descriptive statistics of 1st survey)				
Firm size	Number of employees	1304	868.5	4991.92
Firm age	2009 - year of incorporation of the firm	913	38.600	43.304
Envir. Manag. System	Dummy taking value 1 if environmental management system (EMAS, ISO 14000ff., other EMS) is established	1093	0.510	0.500
Cost no obstacle	High cost or risk as innovation obstacle (1 = strong obstacle; 2 = weak obstacle; 3 = no obstacle)	1165	1.850	0.735
Demand no obstacle	Lack of demand as innovation obstacle (1-3 as above)	1147	2.120	0.786
Information no obstacle	Lack of information as innovation obstacle (1-3 as above)	1111	2.507	0.609
Personnel no obstacle	Lack of qualified personnel as innovation obstacle (1-3 as above)	1137	2.322	0.715
Partner no obstacle	Lack of co-operation partners as innovation obstacle (1-3 as above)	1103	2.598	0.561
Rigidities no obstacle	Organizational rigidities within the firm as innovation obstacle (1-3 as above)	1096	2.605	0.609
Capital no obstacle	Lack of financial/venture capital as innovation obstacle (1-3 as above)	1104	2.481	0.674
Legal no obstacle	Legal procedures as innovation obstacle (1-3 as above)	1112	2.433	0.676
subsidies no obstacle	Inadequate government support as innovation obstacle (1-3 as above)	1112	2.309	0.733
Objective new products	Creation of new products for outdated products as innovation objective (from 1 = very important to 5 = not important)	1014	2.276	1.407
Objective more products	Enlargement of the product range as innovation objective (1-5 as above)	1041	1.902	1.006
Objective market	Maintenance or enlargement of current markets as innovation objective (1-5 as above)	1049	1.754	0.901
Objective new market	Creation of new markets as innovation objective (1-5 as above)	1020	2.182	1.149
Objective technology	Creation of technological leads as innovation objective (1-5 as above)	1044	1.776	0.999
Objective cost	Reduction of production costs as innovation objective (1-5 as above)	1041	2.008	1.094
Determinant technology	Creation of technological leads as innovation determinant (from 1 = very important to 5 = not important)	679	2.099	1.206
Determinant market	Maintenance or enlargement of current markets as innovation determinant (1-5 as above)	677	2.383	1.259
Determinant new markets	Creation of new markets as innovation determinant (1-5 as above)	680	2.625	1.332
Determinant networks	Network activities (e.g. with universities) as innovation determinant (1-5 as above)	667	3.349	1.144
Determinant firm	Firm-internal factors as innovation determinant (1-5 as above)	677	2.242	1.054
Determinant energy costs	Reduction of energy and resource costs as innovation determinant (1-5 as above)	686	1.821	1.062
Determinant environmental regulation	Environmental policy framework conditions as innovation determinant (1-5 as above)	669	2.819	1.179
Determinant subsidies	Direct or indirect government support measures as innovation determinant (1-5 as above)	664	3.398	1.213
Determinant demand	Demand from and image vis-a-vis customers as innovation determinant (1-5 as above)	684	2.326	1.104
Determinant society	Social pressure or image as innovation determinant (1-5 as above)	679	3.103	1.137

Table 2: Firm size and sector shares in the sample and the survey response

	Share in total sample (in%)	Share in survey response (in%)
Less than 150 employees	29.8	35.0
151-500 employees	30.2	33.4
More than 500 employees	40.0	31.6
Mining and quarrying	0.8	0.7
Food and tobacco	10.0	8.1
Textile and leather	4.3	4.6
Wood products	2.3	2.3
Pulp and paper	2.8	3.9
Publishing and printing	4.5	3.5
Coke, petroleum, nuclear fuel	0.5	0.8
Chemical products and fibres	6.0	6.9
Rubber and plastics	5.3	5.7
Non-metallic mineral products	3.8	5.9
Basic metals	3.6	4.1
Fabricated metal products	9.6	9.0
Machines and equipment	14.1	14.6
Office machinery	0.7	0.2
Electrical machinery and apparatus	4.7	4.6
Radio, TV, communication equipment	1.9	2.4
Medical, precision, optical instruments	3.7	4.1
Motor vehicles	2.8	2.4
Other transport equipment	1.1	1.2
Furniture, other manufacturing	3.3	3.3
Recycling	0.6	0.5
Electricity, gas and water supply	5.8	4.9
Construction	8.0	6.2

Table 3: Using key words to identify eco-patents

Key words	Hits before reading	Key words	Hits after reading
recycl	802	exhaust gas	486
waste	615	waste	447
dust	607	recycl	274
exhaust gas	594	dust	216
carbon dioxide	334	fuel cell	139
emission	333	emission	129
CO2	286	Abgas	115
contamina	256	pollut	106
compost	189	NOx	105
fuel cell	152	CO2	104
heat insula	144	contamina	104
carbon monoxide	144	sludge	97
Abgas	138	flue gas	92
flue gas	125	nitrogen ox	89
pollut	117	carbon dioxide	87

Source: PATSTAT

Table 4: The determinants of general innovations and patenting

	Model 1a	Model 1b	Model 1c
Hypotheses tested	I	I	I
Model type	Probit	Random-effects probit	Negative binomial
Dependent variable	Innovations (vs. no innovations)	Innovations (vs. no innovations) – both surveys	Patentvalue
Firm size	0.000 (0.000)**	0.001 (0.001)***	1.087 (0.097) ***
Firm size x time dummy		0.000 (0.000)	
Firm age	0.001 (0.001)		-0.002 (0.002)
Cost no obstacle	-0.152 (0.085)*	-0.081 (0.099)	0.330 (0.158)**
Cost no obstacle x time dummy		-0.028 (0.156)	
Demand no obstacle	0.298 (0.072) ***	0.470 (0.107)***	0.222 (0.139)
Demand no obstacle x time dummy		-0.124 (0.151)	
Information no obstacle	-0.110 (0.105)	Not asked in 2nd survey	0.044 (0.199)
Personnel no obstacle	-0.081 (0.086)	Not asked in 2nd survey	-0.121 (0.151)
Partner no obstacle	0.221 (0.112)*	Not asked in 2nd survey	0.111 (0.203)
Rigidities no obstacle	0.171 (0.098)*	Not asked in 2nd survey	0.256 (0.193)
Capital no obstacle	0.146 (0.091)	Not asked in 2nd survey	0.185 (0.174)
Legal no obstacle	0.020 (0.090)	Not asked in 2nd survey	0.240 (0.175)
Subsidies no obstacle	-0.101 (0.086)	Not asked in 2nd survey	-0.090 (0.143)
Time dummy		-0.014 (0.387)	
Constant	-0.353 (0.399)	0.156 (0.255)	-8.253 (1.109)***
Observations	739	1511 (1316 groups)	655
Log-likelihood	- 339.80239	-786.87424	-993.87084
Wald test	37.39	38.65	153.75

Robust standard errors in parentheses; * p<0.1 , ** p<0.05 , *** p<0.01; rho=0.590*** (model 1b)

Table 5: The differences between innovation objectives (innovators vs. eco-innovators; firms with patents vs. firms with eco-patents)

	Model 2a	Model 2b	Model 2c
Model type	Probit	Random-effects probit	Negative binomial
Hypotheses tested	IIa	IIa	IIa
Dependent variable	Eco-innovations (vs. other innovations)	Eco-innovations (vs. other innovations)– both surveys	Ecopatentvalue
Firm size	0.160 (0.046)***	0.000 (0.000)***	1.055 (0.096)***
Firm size – additional effect		0.000 (0.000)	0.212(0.114)
Firm age	0.000 (0.001)		- 0.05 (0.002)**
Firm age – additional effect			- 0.004 (0.007)
Envir. Manag. System	0.622 (0.113)***		0.002 (0.212)
Envir. Manag. System – additional effect			- 0.816 (0.509)
Objective new products	0.040 (0.043)	-0.010 (0.058)	-0.375 (0.094)***
Objective new products – additional effect		0.166 (0.092)*	0.359 (0.181)**
Objective more products	- 0.023 (0.059)	0.122 (0.087)	-0.057 (0.111)
Objective more products – additional effect		-0.061 (0.135)	-0.021 (0.267)
Objective market	0.096 (0.069)	0.115 (0.101)	- 0.035 (0.124)
Objective market – additional effect		-0.079 (0.161)	0.153 (0.331)
Objective new market	0.006 (0.052)	0.007 (0.076)	0.017 (0.100)
Objective new market – additional effect		-0.089 (0.125)	-0.186 (0.307)
Objective technology	-0.048 (0.058)	-0.193 (0.083)**	-0.521 (0.117)***
Objective technology – additional effect		0.050 (0.124)	0.462 (0.221)**
Objective cost	-0.163 (0.054)***	-0.381 (0.090)***	0.213 (0.114)*
Objective cost – additional effect		0.302 (0.121)**	-0.107 (0.236)
Time effect		-0.664 (0.457)	
Dummy eco-patent			-5.639 (1.136)***
Constant	- 0.571 (0.318)*	1.218 (0.332)***	- 3.613 (0.661)***
Observations	625	1332 (1174 groups)	1250 (625)
Log-likelihood	-358.61506	-801.6005	- 1257.7002
Wald test	73.39	32.97	525.46

Robust standard errors in parentheses; * p<0.1 , ** p<0.05 , *** p<0.01; additional effects refer to time in model 2b and environment in model 2c; rho=0.679*** (model 2b)

Table 6: The determinants of various kinds of eco-innovations and eco-patenting

	Model 3a	Model 4a	Model 5a	Model 6a	Model 7
Model type	Ordered probit	Probit	Probit	Ordered probit	Negative binomial
Hypotheses tested	Va,b	IVa,b	III		IVb
Dependent variable	Number of eco-innovations	New-to-market (vs. new-to-firm) eco- innovation	Process (vs. product) eco-innovation	Energy (vs. non-energy) eco-innovation	Value of eco-patent stock
Firm size	0.173 (0.046)***	0.087 (0.051)*	-0.125 (0.059)**	0.058 (0.039)	1.301 (0.131)***
Firm age	0.002 (0.001)**	0.001 (0.001)	-0.000 (0.002)	0.001 (0.001)	- 0.012 (0.006)**
Envir. Manag. System	0.351 (0.134)***	-0.245 (0.148)*	0.097 (0.172)	0.171 (0.122)	- 0.601 (0.509)
Determinant technology	-0.097 (0.061)	-0.317 (0.070)***	0.119 (0.009)	0.074 (0.059)	-0.044 (0.163)
Determinant market	-0.102 (0.072)	0.040 (0.082)	0.031 (0.092)***	-0.135 (0.066)**	0.528 (0.295)*
Determinant new markets	0.029 (0.069)	-0.126 (0.078)	0.178 (0.086)**	-0.089 (0.062)	-0.953 (0.246)***
Determinant networks	0.012 (0.063)	-0.135 (0.072)*	0.079 (0.083)	-0.004 (0.064)	0.269 (0.275)
Determinant firm	-0.048 (0.072)	-0.031 (0.078)	-0.029 (0.091)	0.053 (0.061)	0.045 (0.222)**
Determinant energy costs	-0.106 (0.061)*	0.123 (0.072)*	-0.398 (0.083)***	-0.105 (0.055)*	0.270 (0.211)
Determinant demand	-0.060 (0.062)	-0.064 (0.073)	0.050 (0.084)	-0.002 (0.058)	-0.183 (0.235)
Determinant society	0.005 (0.059)	-0.007 (0.071)	-0.023 (0.087)	0.071 (0.061	0.009 (0.203)
Determinant environ. regulation	-0.041 (0.067)	0.180 (0.074)**	-0.030 (0.081)	0.070 (0.061)	0.418 (0.272)
Determinant subsidies	0.106 (0.062)*	0.009 (0.071)	-0.101 (0.082)	-0.139 (0.059)**	-0.697 (0.256)***
Constant	μ1: 0.538(0.410) μ2: 1.050 (0.411)	0.502 (0.456)	0.452 (0.519)	μ1: -0.492 (0.357) μ2: 0.676 (0.356)	-9.367 (1.66)***
Observations	409	399	349	419	419
Log-likelihood	-397.0113	-237.06111	-178.33299	-432.57901	-138.66161
Wald test	59.39	63.59	65.73	30.38	229.33

Robust standard errors in parentheses; * p<0.1 , ** p<0.05 , *** p<0.01;

Table 7: The determinants of various kinds of eco-innovations and eco-patenting across time

	Model 3b	Model 4b	Model 5b	Model 6b
Model type	Random-effects probit	Random-effects probit	Random-effects probit	Random-effects probit
Dependent variable	Number of eco-innovations – both surveys	New-to-market (vs. new-to-firm) eco-innovation – both surveys	Process (vs. product) eco-innovation – both surveys	Energy (vs. non-energy) eco-innovation – both surveys
Hypotheses tested	Va,b	IVa,b	III	
Firm size	0.000 (0.000)**	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)**
Firm size x time dummy	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Determinant technology	-0.161 (0.109)	-0.328 (0.094)***	0.146 (0.114)	0.041 (0.070)
D. technology x time dummy	0.234 (0.185)	-0.014 (0.130)	-0.041 (0.190)	-0.348 (0.137)**
Determinant market	-0.240 (0.142)*	0.010 (0.926)	0.377 (0.169)**	-0.215 (0.090)**
D. market x time dummy	0.139 (0.216)	-0.118 (0.148)	-0.208 (0.217)	0.238 (0.152)
Determinant new markets	0.060 (0.119)	-0.182 (0.092)**	0.320 (0.149)**	-0.090 (0.083)
D. new markets x time dummy	0.998 (0.197)	0.220 (0.142)	0.151 (0.192)	0.259 (0.156)*
Determinant networks	-0.014 (0.115)	-0.079 (0.830)	0.030 (0.149)	0.059 (0.077)
D. networks x time dummy	-0.103 (0.177)	0.039 (0.126)	0.242 (0.198)	-0.118 (0.130)
Determinant firm	-0.028 (0.116)	-0.023 (0.084)	-0.522 (0.168)	0.036 (0.079)
D. firm x time dummy	-0.060 (0.194)	0.048 (0.137)	-0.333 (0.212)	0.100 (0.141)
Determinant energy costs	-0.343 (0.139)**	0.124 (0.773)	-0.156 (0.114)***	-0.240 (0.081)***
D. energy costs x time dummy	0.142 (0.192)	0.061 (0.126)	-0.107 (0.190)	0.121 (0.125)
Determinant environmental regulation	-0.067 (0.119)	0.196 (0.091)**	-0.068 (0.115)	0.084 (0.117)
D. environmental regulation x time dummy	-0.214 (0.170)	-0.147 (0.121)	0.167 (0.176)	0.084 (0.117)
Determinant subsidies	0.170 (0.125)	-0.022 (0.081)	-0.086 (0.112)	-0.150 (0.079)*
D. subsidies x time dummy	0.095 (0.153)	0.079 (0.112)	0.015 (0.162)	0.021 (0.110)
Determinant demand	-0.046 (0.114)	-0.044 (0.082)	0.127 (0.116)	0.101 (0.077)
D. demand x time dummy	-0.176 (0.220)	0.014 (0.143)	0.218 (0.222)	-0.075 (0.141)
Determinant society	-0.027 (0.111)	0.015 (0.079)	-0.156 (0.114)	0.055 (0.075)
D. society x time dummy	0.025 (0.181)	0.128 (0.131)	0.003 (0.186)	-0.165 (0.132)
Additional time dummy	-0.608 (0.777)	-0.934 (0.586)	-0.721 (0.834)	0.282 (0.567)
Constant	0.713 (0.472)	0.803 (0.358)	0.115 (0.468)	1.282 (0.362)
Observations	816 (740 groups)	781 (713 groups)	694 (640 groups)	833 (755 groups)
Log-likelihood	-499.20133	-484.51954	-361.80271	-474.12788
Wald test	15.34	30.38	14.99	28.79
rho	0.693***	0.353**	0.580**	0.305*

Annex 1: The differences between innovation objectives – sector level

	Sector	NACE 29		NACE 31-33		NACE 23-28		NACE other	
Independant variable	Dependant variable (model number)	Main	Sector	Main	Sector	Main	Sector	Main	Sector
Firm size	Eco-innovation (2a)	+***	+	+***	+	+***	-	+***	+
	Ecopatentv. (2c)	+***	+***	+***	-	+***	-	+***	-
	Ecopatent – AE eco	+**	+	+	-	+	+**	+	+
Firm age	Eco-innovation (2a)	-	+	+	+	-	+	+	-**
	Ecopatentv. (2c)	-**	+	-*	+	-	+	-	-
	Ecopatent – AE eco	-	-	-	+*	+	-***	-	+*
Envir. Manag. System	Eco-innovation (2a)	+***	-	+***	+	+***	+	+***	-
	Ecopatentv. (2c)	+	-	+	-	-	-	-	+*
	Ecopatent – AE eco	-	-***	-**	+	-	+	-	-
Objective new products	Eco-innovation (2a)	-	+	+	-*	+	+	+	+
	Ecopatentv. (2c)	-***	+***	-***	-	-***	+	-**	-*
	Ecopatent – AE eco	+	+**	+*	-	+	-	+	-
Objective more products	Eco-innovation (2a)	-	-	-	+	-	+	-	-
	Ecopatentv. (2c)	-	+	-	-	+	-	-	+*
	Ecopatent – AE eco	+	-**	-	+*	-	+	+	-
Objective market	Eco-innovation (2a)	+	-	+*	-***	+	+	+	+
	Ecopatentv. (2c)	-	+	+	-	-	-	-	+
	Ecopatent – AE eco	-	+	+	-	-	+	+	-
Objective new market	Eco-innovation (2a)	-	+	+	-*	+	+	+	+
	Ecopatentv. (2c)	+	-	+	-	+	-	-	+
	Ecopatent – AE eco	-	+	-	-	-	-	-	-
Objective technology	Eco-innovation (2a)	-	-**	-	+	-	+	-	+
	Ecopatentv. (2c)	-***	-	-***	-	-***	+	-**	+
	Ecopatent – AE eco	+	+**	+**	-**	+**	-	+*	+
Objective costs	Eco-innovation (2a)	-**	-	-***	+*	-***	+	-**	-
	Ecopatentv. (2c)	+	-	+	+	+**	-	+**	-**
	Ecopatent – AE eco	-	+	-	+	-	-	+	-
Dummy - sector	Eco-innovation (2a)	Na	-	Na	+	Na	+	Na	+
	Ecopatentv. (2c)	Na	-***	Na	+	Na	+	Na	+
	Ecopatent – AE eco	-***	-	-***	-	-***	-**	-***	-

"Ecopatent – AE eco" refers to the additional effect for firms with eco-patents; "Main" refers to the effect for all sectors except the sector under consideration, "Sector" refers to the sector-specific effect

Annex 2: The determinants of various kinds of eco-innovations and eco-patents – sector level

Ind. variable/ Sector		NACE 29		NACE 31-33		NACE 23-28		NACE other	
	Dep. Variable (model number)	Main	Sector	Main	Sector	Main	Sector	Main	Sector
Hypotheses tested		IIb, role of sectors							
Firm size	New-to-market eco-innovation (4a)	+	+	+*	-	+*	-	+	-
	Number of eco-innovations (3a)	+***	-	+***	-	+***	+	+**	+
	Process eco-innovation (5a)	-**	-	-*	-	-	-**	-*	+
	Energy eco-innovation (6a)	+	-	+	-	+	+*	+	-
	Value eco-patent (7)	+	+	+***	+	+***	+*	+	+
Firm age	New-to-market eco-innovation (4a)	+	-	+	+	+	-	+	+
	Number of eco-innovations (3a)	+*	+	+*	-	+	+	+	+

	Process eco-innovation (5a)	-	-	-	-	-	+	+	-
	Energy eco-innovation (6a)	+	+	+	-*	+	-*	-	+*
	Value eco-patent (7)	-	+***	-**	-	+	-***	-	+
Environmental Management System	New-to-market eco-innovation (4a)	-	+	-*	+	-**	+	-*	-
	Number of eco-innovations (3a)	+*	+	+***	-	+*	-	+**	-
	Process eco-innovation (5a)	+	+	+	+	+	+	+	-
	Energy eco-innovation (6a)	+	-	+	+	+	+	+	-
	Value eco-patent (7)	+	-	-	-	-	+	-	-
Determinant technology	New-to-market eco-innovation (4a)	-***	+	-***	+*	-***	-	-**	-
	Number of eco-innovations (3a)	-*	+	-**	+*	-	-	-	-
	Process eco-innovation (5a)	+	-	+	+	+	+	+**	-*
	Energy eco-innovation (6a)	+	+	+	-	+	+	+*	-
	Value eco-patent (7)	+	-**	-	+	-	+	+	-
Determinant market	New-to-market eco-innovation (4a)	+	+	+	-	-	+	+	-
	Number of eco-innovations (3a)	-	+	-**	+***	-	-	-	-
	Process eco-innovation (5a)	+**	+**	+***	+	+***	-	+**	-
	Energy eco-innovation (6a)	-	-	-**	+	-*	-*	-***	+**
	Value eco-patent (7)	+	-***	+	-	+	-	+	+
Determinant new markets	New-to-market eco-innovation (4a)	-	-	-	-	-	-	-**	+
	Number of eco-innovations (3a)	+	-	+	-***	-	+**	-	+
	Process eco-innovation (5a)	+**	-	+*	+	+*	+	+	-
	Energy eco-innovation (6a)	-	-	-	+	-	+	-	-
	Value eco-patent (7)	-	+***	-***	+	-*	-*	-	-
Determinant networks	New-to-market eco-innovation (4a)	-*	-	-	-	-	-	-*	+
	Number of eco-innovations (3a)	-	+	+	-	-	+	-	+
	Process eco-innovation (5a)	+	+	+	-	+	+	+	-
	Energy eco-innovation (6a)	-	+	+	-	+	-	-	+
	Value eco-patent (7)	+	-**	+	-**	-	+	-	+**
Determinant firm	New-to-market eco-innovation (4a)	-	+	-	+	-	+	+	-*
	Number of eco-innovations (3a)	-	-	-	+	-	+	-	-
	Process eco-innovation (5a)	-	-	+	-	+	-	-	+
	Energy eco-innovation (6a)	+*	-*	+	+	+	-	+	+
	Value eco-patent (7)	+	-	+	+**	+	-	+	-***

Determinant energy costs	New-to-market eco-innovation (4a)	+*	-	+*	-	+	+	+**	-
	Number of eco-innovations (3a)	-**	+	-**	+	-	+	-**	-
	Process eco-innovation (5a)	-***	-	-***	-	-***	-*	-***	+**
	Energy eco-innovation (6a)	-*	+	-	-	-	+	-	-
	Value eco-patent (7)	+	+*	+	-**	+	-	+	-***
Determinant demand	New-to-market eco-innovation (4a)	-	-	-	-	-	-	-	+
	Number of eco-innovations (3a)	-	-	-	-	-	-	-	+
	Process eco-innovation (5a)	+	+	+	-	-	+	+	+
	Energy eco-innovation (6a)	-	+	+	+	-	-	+	-
	Value eco-patent (7)	-	-	-	-	-	-	-	+
Determinant society	New-to-market eco-innovation (4a)	-	+	+	-	-	+	+	-
	Number of eco-innovations (3a)	-	+	+	-	+	+	+	-
	Process eco-innovation (5a)	-	-	-	+	+	-	-	+
	Energy eco-innovation (6a)	+	-	+	-	-	+***	+**	-**
	Value eco-patent (7)	+	+	+*	-	+	+*	+	-**
Determinant environmental regulation	New-to-market eco-innovation (4a)	+***	-**	+**	-	+*	+	+	+
	Number of eco-innovations (3a)	-	+	+	-	+	+	+	-
	Process eco-innovation (5a)	-	+**	-	+	+	-	-	-
	Energy eco-innovation (6a)	+	-	+	-	-	+***	+**	-**
	Value eco-patent (7)	+	+	+*	-	+	+*	+	-**
Determinant subsidies	New-to-market eco-innovation (4a)	+	+	-	+	-	+	+	-
	Number of eco-innovations (3a)	+	-	+	+	+	+	+	-
	Process eco-innovation (5a)	-	-	-	+	-	+	-	-
	Energy eco-innovation (6a)	-	-	-**	+	-	-	-**	+
	Value eco-patent (7)	-	-**	-**	-**	-**	-	-	+
Dummy - sector	New-to-market eco-innovation (4a)	Na	+	Na	+	Na	-	Na	+
	Number of eco-innovations (3a)	Na	-	Na	+	Na	+	Na	-
	Process eco-innovation (5a)	Na	-	Na	+	Na	+	Na	+
	Energy eco-innovation (6a)	Na	+**	Na	-	Na	-*	Na	-
	Value eco-patent (7)	Na	+**	Na	+	Na	-	Na	-**

"Main" refers to the effect for all sectors except the sector under consideration, "Sector" refers to the sector-specific effect

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