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The Link between Environmental Innovation, Patents, and Environmental Management

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Abstract:
This paper analyses empirically the relationship between environmental innovations, environmental management and patenting. In particular it tests a number of propositions on how environmental management systems and the interaction with environmentally more or less concerned stakeholders are associated with the probability of firms to pursue innovation in general (measured as patenting behaviour) and specifically environmental innovation (measured as firm self-assessment and based on patent data). In applying a negative binomial as well as binary discrete choice models the relationship is studied using data on German manufacturing firms. As a novel and important insight, the study finds that environmental innovation can be meaningfully identified using patent data and that environmental innovation defined this way is less ubiquitous than self-reported environmental innovation. It also reveals that the implementation level of environmental management systems has a positive effect exclusively on environmental process innovation, whereas it is negatively associated with the level of a firm's general patenting activities. For environmental product innovation and patented environmental innovations a positive relationship with environ-mentally concerned and a negative link with environmentally neutral stakeholders is found.

Key words: Environmental innovations, patents
Jel codes: O31; Q56

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Introduction

End of October 2006, the German Ministry for the Environment Innovation Conference was held in Berlin and opened by a speech of the secretary of state for the environment, Sigmar Gabriel. Whilst environmental issues are certainly at the core of the ministry work it is notable, that the conference did not deal with regulation or standards but with the question of how to promote innovations that also bring about environmental benefits. Gabriel in his opening speech made a strong plea for an innovation-oriented environmental policy and an ecological industry policy demanding that Germany should establish itself as a responsible "energy efficiency and environmental technologist" in the global division of labour between nations. The well attended conference is one example of the increasing concern of policy makers with environmentally-related or socially beneficial innovation activity of firms that provides next to private benefits also for the public good. This recent relevance merits more detailed analysis to better understand variation between individual firms with regard to such innovation activities and to develop a sound empirical evidence base for any policy-making in this field. More specifically, this paper analyses whether environmental management systems and particular managerial activities to reduce negative environmental impacts have a positive association with environmentally-related innovations (in the following short: environmental innovations) and their patenting as well as with patenting in general. In doing so it links important recent fields of environmental policy (namely the promotion of environmental management systems) with the new initiatives on environmental innovations and with industrial policy in particular with regard to patenting and its role in an interaction of environmental and industrial policy.

In order to avoid a common issue with empirical studies, namely their limited comparability, care was taken to ensure as much as possible comparability with previous studies. Furthermore, in order to overcome at least some of the limitations of earlier studies, the empirical analyses used to test the hypotheses developed in this paper are based on a questionnaire specifically targeted towards environmental management and innovation aspects which collects data at the firm level and includes firms with environmental management systems as well as those without such a system.

One gap in extant literature is the limited use of patent data. Such data has been used successfully in other studies in technology and innovation research to proxy for innovatory activity (e.g. Agrawal & Henderson, 2002; OECD, 1994). Therefore, this study for the first time attempts to use data on patented environmental innovations to address environmental innovations and their determinants. Such an approach could be superior because it only includes innovation that were significant enough to be patentable and therefore would focus on a narrower set of more radical environmental innovations by excluding incremental environmental innovations which only represent very minor inventive steps.

Review of the literature

Environmental innovations have been defined as "… measures of relevant actors (firms, …, private households), which: (i) develop new ideas, behaviour, products and processes, apply or introduce them, and; (ii) contribute to a reduction of environmental burdens or to ecologically specified sustainability targets" (Rennings, 2000: 322). Rennings (2000) furthermore shows that from (ii) the double externality characteristic of environmental innovations can be derived, which can also be used to delineate them from other innovations. Double externality here means that environmental innovations have, next to the positive externalities from spillovers which are common to all innovations, additionally the characteristic of leading to a reduction of external environmental cost as a negative externality). In essence, the definition is about the relationship between technology and the environment and the fundamental role technology and innovations can take in reducing environmental impacts in industrial societies (Foray & Grübler, 1996).

A number of empirical studies have attempted to identify determinants of environmental innovation at the firm level and for aggregated industries (Brunnermeier & Cohen, 2003; Hemmelskamp, 1999; Jaffe & Palmer, 1997; Rehfeld *et al.*, 2007; Rennings *et al.*, 2005; Rennings *et al.*, 2006; Ziegler & Rennings, 2004). For environmental product innovations (measured through survey items aggregated to factor scores), Hemmelskamp (1999) finds a U-shaped relationship with firm size as it is suggested generally by Schumpeter (1934, 1943) but also doubted by Scherer (1992) based on an evaluation of all relevant studies on the influence of firm size on innovation activities until then.[1] A limitation of the research of Hemmelskamp (1999) is that the underlying Mannheim Innovation Panel survey which generated empirical data that was not specifically oriented towards environmental innovations and did not include patent information (Rehfeld *et al.*, 2007). Rennings *et al.* (2005, 2006) analyse in their broad-based empirical survey the effects of environmental management systems (EMS) on firm-level innovation activities and competitiveness based on the European Eco-Audit and Management Scheme (EMAS). A main conclusion from the study is the need

[1] This is also the reason for not including the square of firm size in the estimations to follow.

for better linkage of environmental and innovation management. Ziegler and Rennings (2004) analyse a sample of German firms (n=588) with regard to the effect of EMS and of specific measures such as life cycle analysis or existence of recycling systems on environmental product or process innovations. They apply binary Probit and multinomial Probit models but find only limited effects of EMS certification.

Jaffe and Palmer (1997) analyse the influence of environmental expenditures on innovation activities based on panel data for the U.S. manufacturing sector. They find a positive influence of environmental expenditure on future research and development (R&D) expenditure, but not on the number of patent applications. Brunnermeier and Cohen (2003) criticise that in this approach that the simultaneous influence of environmental expenditure on R&D expenditure and patent applications is not addressed and that the number of patent applications did not focus on environmental innovations only.

Exploratory analysis of environmental innovation patenting

In order to improve on the state of the research as identified in the literature, this study attempted to identify patented environmental innovations for a dataset of firms (described in Section 5) that responded to a survey on environmental management and innovation in 2001. The aim of this exploratory analysis was to clarify if and in which way environmental innovations can be identified from patent data and whether patent data on environmental innovation can be used for an empirical analysis. For the firms in the data set, searches were carried out to identify patents granted by application date for the period of 1999 to 2005. The data sources used is the database DEPATISnet (www.depatisnet.de) of the German Patent and Trademark Office (DPMA) which contains all patent applications in Germany. Since a large number of firms in the sample were small and medium sized German firms and since such firms tend to apply initially in Germany for patent protection, this was considered a better way to ensure as full as possible data coverage, than to rely on the database of the European Patent Office.

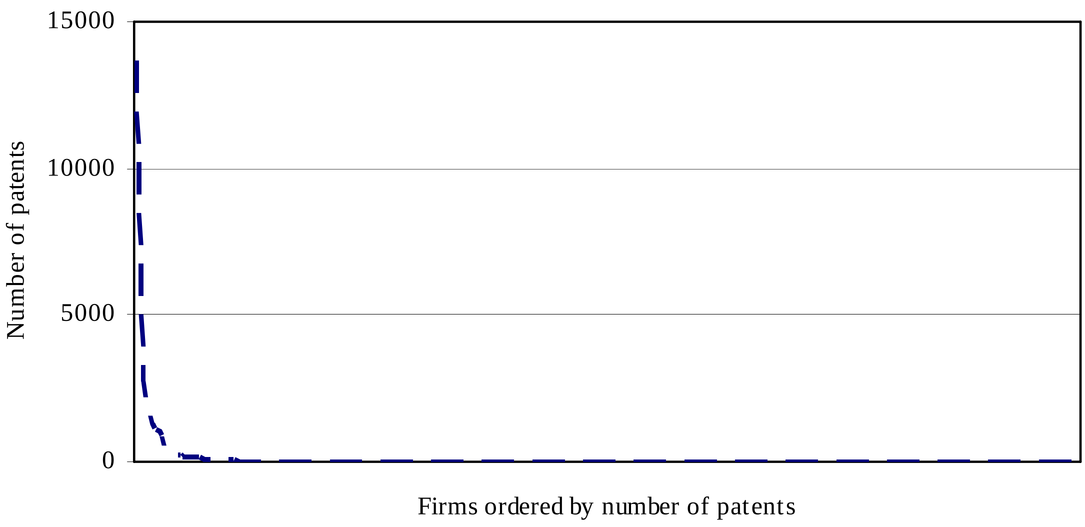
The DEPATISnet database contains the title of the patent, the applying firm and its address, the name of the inventor, the application date and the application number as well as the date when the patent was published, once granted and a brief abstract of the patent. Data searches were carried out manually by name of the applying firm together with word stems and obvious variations of the name. The address of the firm (including telephone and telefax numbers) was used to ensure correct matching. Uncertain matches were furthermore checked with regard to the contents of abstracts and the inventor names.

In cases, where a search with the full firm name did not yield any patents, searches were also carried out with the individual parts of the firm name. The resulting patent data set was initially analysed in general terms in order to ensure it is representative and consistent with stylized facts found for patent data. Subsequently, in order to identify environmental innovations, a qualitative analysis was carried out by searching the abstracts of the patents using a number of environmentally related terms. This was done to identify the basic occurrence and frequency of patents with an environmentally related content and to analyse to which degree such patents fit with the abstract definition of environmental innovations as provided in Section 2.

Overall, data on 43385 granted patents that were applied for from beginning of 1999 to end of 2005 was collected. Ordering the number of firms by the number of patents yields the typical hyperbolic curve, i.e. many firms have no or very few patents and few firms with a high number of patents. This is consistent with earlier studies on the distribution of patents across firms (Lotka, 1926; de Solla Price, 1976) and hence provides further evidence that the sample can be considered largely representative for the distribution of patents in the German manufacturing industry as a whole.

FIGURE 1

Distribution of number of patents by firms' overall patenting activity



Anaylsing patents by industry it becomes clear that firms in the chemical industry, the metal products industry and the automotive industry have the highest number of patents in the data set. Opposed to this, only few patents are found in mineral oil processing, the transport industry and the textile industry, which is consistent with earlier studies on differences in the propensity to patent across industries (Cohen *et al.*, 2001).

After analysing the patent data set in general terms, a qualitative analysis was carried with regard to environmental innovations and their link to patenting activity of firms in th data set. In a first step, the titles and abstracts of the 43385 patents included in the data set were searched with a number of terms that cover all significant environmental aspects as identified by the International Standards Organisation (ISO, 1999). These terms were (in German): water consumption (Wasserverbrauch), ressource consumption (Ressourcenverbrauch), hazardous waste (Sonderabfall), soil pollution (Bodenbelastung), waste water (Abwasser), air pollutant (Luftschadstoff), noise emission (Lärmemission), odour emission (Geruchsemission), landscape damage (Landschaftseingriff) and accident risk (Unfallrisiken). A separate search was run for each of them.

The results shown in Table 1 indicate that those terms are very rarely mentioned in the titles and abstracts of the patents analysed and in fact only concern six of all granted patents that were applied for during 1999 to 2005. One reason for this result could be that the complexity of the terms used for this search is too high, or that environmental innovations are not identified in patent data in terms of environmental aspects, but rather through more generic terms referring to performance improvements.

TABLE 1

Occurrence and frequency of terms relating to environmental aspects [a]

Term	**Patents, top 10 firms**	**Patents, other firms**
Water consumption	0	0
Ressource consumption	1	0
Hazardous waste	0	0
Soil pollution	0	0
Waste water	4	1
Air pollutant	0	0
Noise emission	0	1
Odour emission	0	0
Landscape damage	0	0
Accident risk	0	0

[a] Note: Top 10 firms are those ten firms that have the largest number of patents

One patent mentioning wastewater is held by a medium-sized German firm having the legal form of a GmbH & Co. KG. It refers to a filter material and refers to the term in the abstract as follows: „*It is a filter material to filter flowing media that carry impurities, such as a liquid like waste water or a gas like exhaust air …*“.[2]

In order to substantiate the initial findings regarding the patenting of environmental innovations whilst addressing the methodological concerns raised as possible explanations for them, a second analysis was carried out using different terms. These terms related to process aspects and performance improvements were (in German): recycling (Recycling), consu-mption (Verbrauch), emission (Emission), substitution (Substitution), reduction, (Reduktion), energy (Energie), resource consumption (Ressourcenverbrauch) and efficiency (Effizienz). Separate searches were gain run for all of them and Table 2 shows the results of these.

TABLE 2

Occurrence and frequency of terms relating to process and performance aspects

Term	**Patents, top 10 firms**	**Patents, other firms**
Recycling	4	1
Consumption	18	9
Emission	20	3
Substitution	4	1
Reduction	87	19
Energy	357	50
Efficiency	12	6

Overall, as hypothesized, the use of less complex terms increases the number of patents that are found to contain these terms. It becomes also clear from Table 2 (as was already a tendency in Table 1) that firms which have significant patent activity (and are also large corporations) patent more than smaller and medium-sized firms. For example, the term „resource consumption is found in a patent of a large German car manufacturer. The patent (applied for in 2003) for a process and means for air conditioning in stationary mode states that: *“… that air conditioning is only done during a necessary minimum period prior to the arrival of the user at the vehicle, which avoids unnecessary resource consumption”*. Overall, the exploratory analysis found that only a small number of firms hold patents for environmental innovations. Taking the total of 598 patents in which the search terms occurred, only 1.4% of all patents in the data set are environmentally related and represent 41 firms of the 342 in the data set (i.e. 12%). Given the considerably higher number of firms stating that they develop more environmentally sound products as well as implementing

[2] In all cases translations of patent abstracts from German are by the author.

integrated environmentally technologies this is surprising. One reason for the discrepancy could be that many environmental innovations are protected by means other than patenting, such as secrecy, lead time or defensive publishing. The latter is particularly relevant when a firm is only interested in being able to use a specific innovation, but does not want to exclude others from its use (Johnson, 2004). Another reason could be that environmental innovations are supported by public funding that is only granted under the condition that the results are made public, which implies that patenting is not possible. Thirdly, the sample of manufacturing firms for which the patent data was collected only contains a very small number of firms whose core business activity is development, production or selling of dedicated environmental technology. To the degree that patenting of environmental innovations as defined by the search terms used mainly occurs in environmental technology firms only a small share of such patents would have found its way into the database analysed here. Fourthly, it may be that many environmental innovations include an inventive step that is so small, that patenting is not feasible. In this case, measuring environmental innovations by means of specific patents is a more conservative approach that identifies only the more radical environmental innovations.

From the exploratory analysis of patents it became clear, that whilst patented environmental innovations are in many ways the most desirable measure of environmental innovation activities their use is difficult for the data at hand. Therefore it was decided, to only use them in terms of a binary variable on whether environmental innovation was patented or not. The binary variable equals one if a firm has at least one patent that has been identified by using the search terms introduced earlier (regardless of the term being a simple or more complex one). Based on this it is found, that 200 firms do not patent at all. 41 firms have non-environmentally related patents and at least one environmentally-related patent, whereas 80 firms have patents in general, but no environmentally-related patent. 21 firms responded completely anonymously to the survey and could thus not be related to any patent data.

In addition, indicators of environmental innovation activities that have been collected during the initial survey in 2001 together with data on overall patenting of the firms in the data set are used as the dependent variables of the analysis. The use of survey indicators is a common approach e.g. also pursued in the European Community Innovation Survey (Smith, 2005) and the analysis of the association of environmental management activities with overall patenting activity can provide insights in the more indirect workings of such activities. These can be related to the role of EMS and environmental management activities as complementary assets or in terms of increasing absorptive capacity in general which may be associated with higher overall patenting.

Model development and propositions

This paper addresses two aspects at the environment-innovation nexus. Firstly this is that environmental management systems (EMS), cooperation and particular activities, such as cooperation may have a positive influence on the probability of firms to pursue environmental innovations. Secondly in an attempt to mitigate weaknesses of survey indicators for environmental innovation, patent data is involved to enable insights based on a more focussed measure of environmental innovation and to compare these to survey indicators.

There has been considerable research into the role of EMS in recent years (e.g. Hamschmidt & Dyllick, 2001; Rennings *et al.*, 2003, 2006; Rennings et al., 2005) with the general conclusion being that a "soft" positive EMS influence on less tangible factors such as innovatory activity or reputation of firms exists (e.g. Hamschmidt & Dyllick, 2001; Rennings *et al.*, 2005). This implies that the level of EMS implementation should have a positive effect on firms' propensity to carry out environmental innovations, leading to a first proposition.

> *Proposition 1: A higher level of EMS implementation by a firm is associated with higher propensity and/or activity level of that firm to carry out environmental process or product innovation (stated or in terms of patenting of environmental innovations).*

> *Proposition 2: The association should be less positive for activity levels as concerns patenting activity in general compared with activity or patenting specifically with regard to environmental innovation.*

Whether this theoretically derived relationship can be identified empirically depends on the way the level of EMS implementation is measured. For example, Rehfeld *et al.* (2007) and Ziegler and Rennings (2004) measure implementation based on whether firms have or do not have certification or verification according to ISO 14001 or EMAS, the EU Eco-Management and Auditing Scheme. This may be problematic, because approaches rooted in institutional economics (e.g. Russo, 2001) derive from the existence of asymmetric information in the case of EMS certification incentives for firms to behave opportunistically. Also, neo-institutional organisational theory (DiMaggio & Powell, 1983) that certification is a symbolic gesture with little influence on environmental innovations but rather motivated out of institutional isomorphism and mimicry behaviour. Opposed to this the resource based view (Wernerfelt,

1984) suggests that EMS implementation enables the development of strategic resources and competitive advantages which have a positive influence on firms' innovatory capabilities and thus on the extent of environmental innovation. In this view, EMS certification could be interpreted as signalling about competencies of the firm. However even this being the case, the positive influence on innovatory capabilities and extent of environmental innovation in the firm essentially is caused by EMS implementation and certification only credibly signals this fact, but is not causally responsible for it.

From these considerations it becomes obvious, that for the purposes of addressing Proposition 1, it would be desirable to measure the level of EMS implementation independent of certification. Therefore, to measure the EMS influence, an index variable was defined based on a number of individual EMS elements. This was defined as the sum of activities based on ten elements.[3]

Next to EMS, cooperation activities with environmentally oriented or neutral cooperation partners may be of relevance for innovation and patenting activity with regard to the environment. A suitable approach for classifying such partners the stakeholder theory which is based on the assumption that firms are permanently in an exchange situation with stakeholders and need to take this into account (Freeman, 1984; Donaldson & Preston, 1995). As concerns innovation, this implies two relevant roles of stakeholders. Firstly, they are a source of knowledge that can support the innovation process of the firm. This role leads directly to the large body of literature on R&D cooperation, for example with universities or end users (Agrawal & Henderson, 2002; Hart & Sharma, 2004; von Hippel, 1988; Harhoff *et al.*, 2003). Secondly, stakeholders can object to specific innovation activities, for example because a specific stakeholder group may be concerned about negative effects caused by the realisation of innovation and may therefore object it (Hall & Martin, 2005). Whilst both aspects have been treated in separate works (e.g. Ayuso *et al.*, 2006; Belderbos *et al.*, 2004) no study to date has integrated them in an empirical analysis together with other determinants of environmental innovations. To contribute to the knowledge about determinants of environmental innovation beyond EMS and environmental management activities this is done therefore in this research.

[3] The ten EMS elements were: written environmental policy, procedure for identification and evaluation of legal requirements, initial environmental review, definition of measurable environmental goals, programme to attain measurable environmental goals, clearly defined responsibilities, environmental training programme, environmental goals are part of a continuous improvement process, separate environmental/health/safety report or environmental statement and audit system to check environmental programme. The scale ranged from zero (no activity carried out) to 10 (all listed activities carried out).

Potential cooperation partners can be classified based on stakeholder theory in terms of being predominantly environmentally concerned, partly environmentally concerned or environmentally neutral (e.g. Göbel, 1995; Figge *et al.*, 2002; Schaltegger & Dyllick, 2002 Post *et al.* 2002; Waddock *et al.* 2002; Hall & Vredenburg, 2003). This results in three groups of stakeholders as laid out in Table 4. The groups are included as explanatory variables in the analysis by calculating for each group an index of cooperation intensity as the average of the cooperation intensity (measured on a 3-point scale as not at all, rarely or frequently) across all stakeholders in that group. Cronbach's Alpha for all groups is larger than 0.77 which indicates a sufficiently high internal consistency and reliability.

TABLE 3

Groups of stakeholders relevant as cooperation partners for R&D

Predominantly environmentally concerned stakeholders (Alpha = 0.81)	Partly environmentally concerned stakeholders (Alpha = 0.77)	Environmentally neutral stakeholders (Alpha = 0.80)
Waste disposal firms	Scientific institutions	Users of the product
Recycling firms	Competitors	Suppliers of raw materials
Consumer (protection) associations		Intermediate product suppliers
Trade unions		External consultants
Government or enforcement agencies	Owners	Commercial or industrial customers
Environmental NGOs	Trade associations	Retail customers

Based on this classification and the extant literature referred to above, further propositions can be made.

Proposition 3: Cooperation with predominantly environmentally concerned stakeholders is positively associated with environmentally-related innovation activities and patenting, especially as concerns patenting of environmental innovations.

Proposition 4: Cooperation with partly environmentally concerned stakeholders is not significantly associated with environmentally-related innovation activities and patenting, especially as concerns patenting of environmental innovations.

Proposition 5: Cooperation with environmentally neutral stakeholders is negatively associated with environmentally-related innovation activities and patenting, especially as concerns patenting of environmental innovations.

Data set and methodology

The empirical analysis for which results are presented in the following section is based on data collected during a survey on the state of environmental management in practice which was complemented by subsequent collection of patent data.[4] The questionnaire asked firms for a self-assessment of their main environmental effects and stakeholder demands; for their innovation and environmental management activities as well as cooperation aspects and for general information about the firm and its structure.

Of the 2000 firms contacted in Germany to complete the questionnaire 342 responded, resulting in a response rate of 17.1%. As can be seen from Table 4 about one third of the responding firms had more than 500 employees and around 33% had 50 to 150 employees.

TABLE 4

Crosstabulation of industry sector and firm size

Firm size	50-150	151-500	grea-ter 501	Un-known	Sector share
Food and tobacco	12	11	12	4	11.4 %
Textile and leather	7	4	4	0	4.4 %
Wood products	1	0	0	0	0.3 %
Pulp and paper	7	3	1	0	3.2 %
Publishing and printing	12	7	4	0	6.7 %
Energy, cokes and oil fuel	0	1	1	0	0.6 %
Chemical products and fibres	9	4	11	0	7.0 %
Rubber and plastics	5	7	4	0	4.7 %
Non-ferrous mineral products	5	6	4	2	5.0 %
Metal products	18	15	11	0	12.9 %
Machines and equipment	12	10	12	1	10.2 %
Office machinery and computers	2	1	1	1	1.5 %
Devices for electricity production	2	2	1	0	1.5 %
Radio, TV and communication equipment	1	0	3	0	1.2 %
Medical, precision and optical instruments	4	1	2	0	2.0 %

[4] The survey questionnaire is available on request from the author.

Motor vehicles, transport products/ transport business	3	2	14	1	5.9 %
Furniture, jewellery	4	4	1	0	2.6 %
Recycling	1	0	0	0	0.3 %
Electrical and optical equipment	6	4	4	1	4.4 %
Other manufacturing & transport business	11	15	22	1	14.3 %
Total across sizes	122	97	112	11	100 %

To assess the representativeness of the responses data of the Bundesanstalt für Arbeit was used (BfA, 2000). As concerns response bias it seems possible that the firms responding to the survey are those that are more active in terms of environmental management activities and environmentally-related R&D cooperation. However, comparing the 10% earliest and latest respondents no significant differences in the mean values of the responses on all items were found other than a slightly higher level of environmental management activities of the latest respondents. As well, the large variation in the responses of individual firms shows that also firms less active in terms of environmental management did respond to the survey. Nevertheless comparing with the Bundesanstalt für Arbeit base data larger firms with more than 500 employees are represented over-proportionally in the responses, whereas firms with 151 to 500 and less than 150 employees are under-represented in the dataset which is however a common finding in company surveys not only on environmental management (Baumast & Dyllick, 2001; Armstrong & Overton, 1977). Overall the number of responses to the survey corresponds to about 4% of the total number of firms in the German manufacturing industry in 2001. 56.9% of the responding firms were solely owned, 35.3% were owned by another company and 7.8% where in another way part of a larger firm.

As concerns response bias, it is possible that the replies received contain over-proportionally many firms that are particularly active in terms of environmental management. Such a bias is a frequent problem of surveys based on written questionnaires (Armstrong & Overton, 1977). However in case of the German responses, the characteristics and response behaviour of early respondents was not significantly different from the late replies, based on comparison of means for all variables used between the first and last 10% of respondents, except for a slightly higher level of environmental activities of the latter.

Two procedures were employed to avoid such bias. Firstly, R&D intensity is the explanatory variable covered by far least well in the data with only 65% of all respondents providing this information. Excluding over 30% of the respondents could introduce sample bias, and in order to avoid this, a dummy variable was included in the analysis if data R&D intensity was missing following the method proposed by Hall and Ham Ziedonis (2001). This allowed including all observations in the analysis. Next to the extremely high share of missing data for R&D intensity, individual missing values for other variables reduce the number of cases that can be included in the multivariate analysis reported in the following.

Secondly therefore, to assess whether this raises concerns with regard to sample selectivity, Heckman selection models are estimated with the selection variable being whether or not an observation was included in the multivariate analysis. This allows assessing whether results differ between the models estimated. However, the stylized facts of the analysis are robust against model choice.

To test the 5 propositions derived in Section 4, negative binomial as well as binary and multivariate Probit models are used. A difference of this research to earlier studies is that it uses as dependent variables data on environmental process and product innovations already carried out by the firm as well as patent data for the same firms and that it breaks out environmentally-related patents separately. Data on whether firms carry out environmentally-related product or process innovations based on their self-evaluation are analysed using a multivariate Probit model. Such a model (Greene, 2003: 714-719) is appropriate when error terms are correlated, after the influence of the explanatory variables in the model is accounted for (Greene, 2003: 717).

The EBEB survey asked in two questions about environmental product and process innovations in general („green" design of a new product in the years 1998-2000 and implementation of cleaner technology during the same period). These were used as the dependent variables in the research. Firms could answer these questions with "yes" or "no" or could choose that the question was not applicable to their circumstances in which case they were excluded from the analysis. Table 5 shows that carrying out environmentally-related product or process innovations is related in the data.

TABLE 5

Link of environmentally-related product and process innovations in the data

Product Process	Ja	Nein	Total
Ja	80	30	110
Nein	34	37	71

A larger share of firms that are not pursuing environmentally-related product innovations are not patenting at all (63% versus 58%), though the difference is not large and the same applies to process innovations (63% versus 57%). This indicates, that environmental innovation is related to patenting activity which makes use of the latter as an additional (and likely more conservative) dependent variable feasible.

Binary Probit models (Greene, 2003; Hair *et al.*, 1998) are applied to binary patent variables based on whether or not firms are patenting in general or specifically as concerns environmental innovations. For the negative binomial model, the total number of patents for the period 1999 to 2004 (corresponding to 41112 patents in total) was used. The reason for excluding patents applied for in 2005 was that those were mostly not granted by the time of data collection (end of first quarter of 2006) and that therefore a considerable number of pending applications might have been missed in the search, since the 18-month period prior to publication of the application was still on-going at the time the search of the search. For patents applied for in 2004, this period had largely seized and therefore 2004 is included in the analysis. Conceptually, the granted patents applied for in 1999 to 2004 are closely related to environmental management activities during the period of 1998 to 2000 for which the survey gathered data and tests for indirect effects of these.

The independent variables for all models were based on prior empirical work in industrial economics (Nguyen Van *et al.*, 2004; Schmalensee, 1989; Wagner, 1992; 1995), innovation economics (Tidd *et al.*, 2005; Ziegler & Rennings, 2004) and environmental management research (e.g. Brío & Junquera, 2003; Lefebvre *et al.*, 2003; Russo, 2001; Wagner & Schaltegger, 2004).

Next to the environmental management variables already introduced in Section 4, they include a significant number of explanatory factors such as firm size, industry membership, and firm legal structure. The existence of a quality management system (QMS) was included since the data show that a larger share of firms with QMS pursues environmentally-related product innovations (64% versus 54% for those not having a QMS) and that the same applies to environmentally-related process innovation (68% versus 57%).

Firm size was measured by the logarithm of the number of employees (in thousands), sector membership through dummy variables based on two-digit NACE codes with firms in the metal products sector being the reference group. Other control variables included were the logarithm of firm age in years and firm legal status (in terms of a dummy variable taking unity value if the firm is solely owned).

In the models using patent data as dependent variable, the research intensity (measured in terms of research and development expenditure as a percentage of total sales) of firms was included as an additional independent variable.

Table A1 provides an overview of the explanatory variables used, Table A2 their descriptive statistics and Table A3 of their correlation.

Empirical results

In the following estimation results for the above models are reported. All tables provide the coefficients estimated, the corresponding standard errors (in parentheses) and significance at usual levels.[5]

TABLE 6

Multivariate Probit model for self-evaluated environmental innovations [a]

Type of environmental innovation	*Process*	*Product*
Food and tobacco	0.15 (0.48)	1.25 (0.56)*
Textile products	1.02 (0.75)	0.81 (0.67)
Wood products	5.80 (0.54)**	5.27 (0.52)**
Pulp and paper products	-0.76 (0.73)	-0.78 (0.75)
Publishing and printing	-0.24 (0.73)	0.90 (0.63)
Chemical products and fibres	0.10 (0.56)	0.93 (0.51) †
Rubber and plastics	-0.36 (0.61)	0.42 (0.62)
Non-ferrous mineral products	-0.26 (0.48)	0.59 (0.63)
Machines and equipment	0.38 (0.45)	0.20 (0.50)
Computing and office machinery	-4.41 (0.50)**	-4.85 (0.46)**
Electrical devices	0.61 (0.82)	0.49 (0.71)
Television and radio equipment	-4.24 (0.48)**	-4.51 (0.44)**
Medical and measurement equipment	0.76 (0.62)	-0.47 (0.79)
Optical equipment	0.94 (0.54) †	-5.55 (0.44)**

[5] Results for the Heckman selection models lead to qualitatively identical results, but are not reported to remain parsimonious and because in the case of correlated dependent variables they only apply approximately. They are available upon request from the author.

Motor vehicles	0.46 (0.60)	-0.17 (0.75)
Furniture manufacturing	-0.42 (0.66)	-0.16 (0.66)
Recycling	5.16 (0.47)**	-5.21 (0.53)**
Other transport products	0.44 (0.83)	-4.55 (0.43)**
Other manufacturing	0.25 (0.45)	0.77 (0.49)
Firm age	0.19 (0.11) †	-0.03 (0.14)
Quality management system	0.15 (0.32)	0.46 (0.33)
Firm size	-0.42 (0.22) †	-0.37 (0.25)
Company in sole proprietorship	-0.12 (0.27)	-0.08 (0.28)
Environmental management system index	0.84 (0.44) †	-0.10 (0.42)
Environmentally concerned stakeholders	-0.39 (0.32)	0.62 (0.32) †
Partly concerned stakeholders	-0.18 (0.32)	0.41 (0.34)
Environmentally neutral stakeholders	0.11 (0.31)	-1.46 (0.37)**
Constant	-0.11 (0.82)**	1.46 (1.02)
Observations	152	
Log likelihood	-146.00	
$r_{\text{process innovation, product innovation}}$	0.46**	
Likelihood ratio test of null hypothesis r=0	8.11**	

[a] Robust standard errors in parentheses

† p < .10

** p < .05

*** p < .01

Table 6 provides the results of the estimation for self-reported environmentally-related innovation activities. As can be seen, based on the corresponding Likelihood Ratio (LR) test, the assumption that the error terms are uncorrelated can be rejected, confirming that the use of multivariate Probit model is more appropriate than estimating two independent binary Probit models. In addition, the model is overall significant.

A number of industry dummies which have been included to address industry-specific influences are significant for both environmental product as well as process innovations. A significant positive association of firm age is found on the likelihood of carrying out a process innovation, as is a negative association of firm size on these types of innovations. The most important finding is however, that Proposition 1 can be confirmed in that EMS implementation has a significant positive association with process innovations. Whilst for product innovations the EMS variable is insignificant, a significant positive association of the cooperation with environmentally concerned and a significant negative association of environmentally neutral stakeholders is found which supports Propositions 3 and 5. Table 7 provides results for the models with patent data as dependent variable. The binary Probit and negative binomial models are all overall significant.

TABLE 7

Binary Probit model and negative binomial models for patents as dependent variable [a]

Dependent variable	*Neg. binom.*	*Probit overall*	*Probit env. patents*
Food and tobacco	-2.21 (0.69)**	-1.33 (0.49)**	-5.79 (0.00)
Textile products	-3.86 (1.17)**	-1.13 (0.62) †	0.61 (0.72)
Pulp and paper products	-0.74 (0.86)	-0.56 (0.59)	-5.32 (0.00)
Publishing and printing	-1.58 (0.82) †	-0.79 (0.52)	-5.43 (0.00)
Chemical products and fibres	0.28 (0.65)	0.20 (0.45)	-0.28 (0.54)
Rubber and plastics	0.53 (0.76)	0.82 (0.49) †	-0.31 (0.60)
Non-ferrous mineral products	0.51 (0.66)	0.26 (0.44)	0.02 (0.62)
Machines and equipment	1.11 (0.65) †	0.74 (0.41) †	0.53 (0.49)
Computing/office equipmt.	0.66 (0.67)	1.06 (0.72)	-6.13 (0.00)
Electrical devices	0.52 (1.00)	-0.65 (0.64)	0.55 (0.75)
Medical and measurement equipment	-1.10 (1.33)	0.17 (0.70)	-5.59 (0.00)
Optical equipment	-0.43 (0.75)	0.10 (0.49)	0.11 (0.67)
Motor vehicles	1.78 (0.59)**	1.26 (0.55)*	0.69 (0.80)
Furniture manufacturing	-0.72 (0.65)	0.38 (0.54)	-4.58 (0.00)
Transport business	-4.35 (0.70)**	-0.51 (0.89)	-6.25 (0.00)
Other transport products	-0.02 (0.72)	0.11 (0.72)	0.69 (0.80)

Other manufacturing	-0.80 (0.52)	-0.32 (0.37)	0.21 (0.47)
Firm age	-0.17 (0.15)	0.02 (0.11)	-0.08 (0.14)
Quality management system	1.02 (0.44)*	0.30 (0.26)	6.42 (0.91) *
Firm size	2.67 (0.21)**	0.77 (0.16)**	0.81 (0.22)**
Company in sole proprietorship	-0.28 (0.33)	0.19 (0.21)	-0.22 (0.32)
Environmental management system index	-1.35 (0.61)*	-0.45 (0.33)	-0.45 (0.57)
R&D intensity	0.01 (0.03)	-0.003 (0.02)	-0.02 (0.02)
R&D missing dummy	-1.15 (2.72)	0.66 (1.75)	1.74 (2.17)
Environmentally concerned stakeholders	0.51 (0.39)	0.19 (0.27)	0.76 (0.33)*
Partly concerned stakeholders	-0.84 (0.42)*	-0.26 (0.24)	-0.59 (0.37)
Environmentally neutral stakeholders	-0.49 (0.36)	-0.27 (0.24)	-0.27 (0.33)
Constant	-4.46 (0.97)**	-2.38 (0.65)**	-9.31 (0.00)
Observations		248	
Log likelihood	-493.24	-115.36	-52.88
Wald test	676.46**	90.36**	35.77*

[a] Robust standard errors in parentheses; model with patented environmental innovations estimated using the "asis" option in STATA (model estimation without this option yields qualitatively identical results)

† $p < .10$

* $p < .05$

** $p < .01$

As in the multivariate Probit model a number of industry dummies are significant in the models reported in Table 7. Firm size in all regressions with patents as dependent variable is strongly significant and positively associated with the dependent variable which indicates that this is a very important determinant which is consistent with extant work (Mansfield, 1986; Cohen & Levin, 1989). Other than this, existence of a certified quality management system in the firm is significantly positively associated with the number of patents in the negative binomial model, but not with whether a firm patents or not. However, QMS certification has a significant positive association with patenting of environmental innovations which may indicate a role of quality management systems as complementary assets to EMS. The EMS variable is insignificant in the binary Probit and significantly negative in the negative binomial model. For patenting of environmental innovations a significant positive association with cooperation with environmentally concerned stakeholders is found.

Discussion

Five propositions were tested in this research in based on multivariate and binary Probit and negative binomial models. Proposition 1 that levels of EMS implementation are positively associated with environmental innovation activities could be partly confirmed in the case of self-reported environmental process innovation where a significant positive association was found. For the number of patents a significant negative association was found and for patenting of environmental innovations no significant association was found. Overall, this evidence tends to contradict Proposition 1 but also points to a difference between environmental and non-environmental innovation activities where the association is more positive and relevant for the former.

Concerning Proposition 2 which proposes a weaker association of EMS implementation with innovation activities overall than with environmentally-related innovation activity it is found that the EMS variable is insignificant in the binary Probit and significantly negative in the negative binomial model, whereas it is insignificant in the binary Probit model with patenting of environmental innovations as dependent variable.

Compared to this it was insignificant for self-reported product innovations and significantly positive for process innovations. These findings generally support Proposition 2 in that the associations for non-environmentally related innovation variables are either insignificant or significantly negative, whereas they are insignificant or significantly positive for environmentally-related innovation variables.

As concerns Propositions 3 to 5, no association is found for patenting in general, other than a significant negative association in the negative binomial model for cooperation with partly environmentally concerned stakeholders which is they only finding not consistent with Proposition 4. Support was found for Propositions 3 and 5 in that the association of research cooperation of environmentally concerned and environmentally neutral stakeholders with patenting in general was insignificant, whereas it was significantly positive and negative, respectively, for environmental product innovation. Also for patenting of environmental innovations, a significant positive association was found of cooperation with environmentally concerned stakeholders, which is consistent with Proposition 3.

Concerning propositions 1 and 2 the finding that EMS do not have an association with product innovation and a negative one with patenting of innovation indicates that their effect is likely limited to processes. If this was the case, it could also explain the negative association with the number of patents since patenting would seem more likely for products to be offered on the market, rather than processes operated within the firm. In this sense EMS could have the effect of "crowding out" patenting as an appropriability mechanism in that the implementation of an EMS leads to more process innovation which is patented less frequently but enables competitive advantages that were previously only realised by means of patented product innovations. Assuming that these are not needed any more due to the higher level of process innovation, it would explain why a negative association of EMS implementation with the level of patenting activities is found.

The insignificance of research intensity is possibly due to low number of observations for which data was available leading to larger standard errors (i.e. less precise estimation) implying that coefficient estimation is unbiased, but not efficient (only 171 of 248 observations in the multivariate analysis had data available, equalling to 31% missing values). An alternative explanation could be that the relationship of patenting and research intensity is non-linear as e.g. suggested by Scherer (1984) and Hagedoorn and Duysters (2002). Some indication of this being the case is provided by an alternative model specification including also the squared term of research intensity. In this alternative model, for patenting in general (in both, the binary Probit and negative binomial models) a positive coefficient for the linear and negative one for non-linear term is found, though in all cases the coefficients are not statistically significant.

Finally, a methodological insight is, that the use of EMS certification as a measure for EMS implementation (rather than an activity-based measure as used here) is a possible explanation for its insignificant effect on environmental innovations in other empirical studies (e.g. Ziegler & Rennings, 2004). EMS as it seems mainly work through their implementation level but not by means of certification which takes place after implementation or even not at all.[6]

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Appendix

Table A1 provides a summary of the definition of all variables used in the empirical analysis. Table A2 provides descriptive statistics for all variables used and Table A3 correlations for these.

TABLE A1

Summary of variable definitions for variables used in the empirical analysis

Concept	Variable	Description	Type
EMS and stakeholder-related variables	Environmental management system index	Index measuring the implementation level of an environmental management system in the firm	conti-nuous (cont.)
	Environmentally concerned stakeholders	Level of cooperation (between 0 and 2) of the firm with environmentally concerned stakeholders	cont.
	Environmentally neutral stakeholders	Level of cooperation (between 0 and 2) of the firm with environmentally neutral stakeholders	cont.
	Partly environmentally concerned stakeholders	Level of cooperation (between 0 and 2) of the firm with partly environmentally concerned stakeholders	cont.
QMS	Quality system	Dummy taking value 1 if no QMS is acquired	dummy
Sector control variables	Food / tobacco	Firm in food and tobacco sector	dummy
	Textiles	Firm in textile products sector	dummy
	Pulp and paper	Firm in pulp and paper products sector	dummy
	Printing	Firm in printing and publishing sector	dummy
	Energy, cokes and oil fuel	Firm in energy, oil and nuclear fuels sector	dummy
	Chemicals	Firm in chemicals and fibres sector	dummy
	Rubber & plastic	Firm in rubber and plastic products sector	dummy
	Non-ferrous	Firm in non-ferrous mineral products sector	dummy
	Machines equipment	Firm in machines and equipment sector	dummy
	Electrical & op-tical equipment	Firm in electrical and optical products sector	dummy
	Other transport products	Firm in transport products sector (except automotives)	dummy

	Metals products	Firm in metals products sector (reference)	dummy
	Other manufac-turing products	Firm in sector producing other manufacturing products	dummy
	Computing/office equipment	Firm in sector producing computing or office equipment	dummy
	Wood products	Firm in sector producing wood products	dummy
	Medical and measurement equipment	Firm in sector producing medical and measurement equipment	dummy
	Television and radio equipment	Firm in sector producing television and radio equipment	dummy
	Recycling	Firm in the recycling sector	dummy
	Motor vehicles	Firm in sector producing motor vehicles	dummy
	Transport business	Firm in transport business sector	dummy
	Furniture manufacturing	Firm in sector producing furniture	dummy
	Electric devices	Firm in sector producing electric devices	dummy
Firm size	No. employees	Number of employees (in thousands)	cont.
Other control variables	Firm age	Logarithm of firm age in years	cont.
	Firm legal status	Dummy of value 1 if firm is solely owned	dummy
	R&D intensity	Share of research expenditure in total sales and dummy variable taking value of 1 if data on R&D intensity was missing	cont. or dummy

TABLE A2

Descriptive statistics for independent variables

Variable	n	Minimum	Maximum	Mean	Standard deviation
Company in sole proprietorship	330	0.00	1.00	0.58	0.49
Environmentally concerned stakeholders	317	0.00	2.00	1.04	0.56
Environmentally neutral stakeholders	313	0.00	2.00	1.06	0.59
Partly environmentally concerned stakeholders	302	0.00	2.00	0.83	0.57
R&D intensity	342	0.00	100.00	38.12	45.83
Dummy for missing R&D intensity data	342	0.00	1.00	0.35	0.48
Decadic logarithm of firm age	316	0.69	6.51	3.72	1.06
Decadic logarithm of firm size	329	1.14	5.29	2.56	0.73
Food and tobacco	342	0.00	1.00	0.11	-
Textile products	342	0.00	1.00	0.04	-
Wood products	342	0.00	1.00	0.002	
Pulp and paper products	342	0.00	1.00	0.03	-
Publishing and printing	342	0.00	1.00	0.07	-
Energy, cokes and oil fuel	342	0.00	1.00	0.01	-
Chemical products and fibres	342	0.00	1.00	0.07	-
Rubber and plastics	342	0.00	1.00	0.05	-
Non-ferrous mineral products	342	0.00	1.00	0.05	-
Metal products	342	0.00	1.00	0.13	-
Machines equipment	342	0.00	1.00	0.10	-
Electrical and optical equipment	342	0.00	1.00	0.04	-
Computing/office equipmt.	342	0.00	1.00	0.01	-
Electrical devices	342	0.00	1.00	0.01	-
Medical and measurement equipment	342	0.00	1.00	0.02	-
Television and radio equipment	342	0.00	1.00	0.01	-
Motor vehicles	342	0.00	1.00	0.03	-
Furniture manufacturing	342	0.00	1.00	0.03	-
Transport business	342	0.00	1.00	0.01	-
Recycling	342	0.00	1.00	0.02	-
Other transport products	342	0.00	1.00	0.02	-
Other manufacturing	342	0.00	1.00	0.14	0.34
Environmental management system index	328	0.00	1.00	0.41	0.38
Existence of a quality standard	332	.00	1.00	0.75	0.43

TABLE A3

Correlation of independent variables (n=248)

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Environmental management system index (1)	1								
Environmentally-concerned stakeholders (2)	-0.39**	1							
Environmentally-neutral stakeholders (3)	-0.37**	0.56**	1						
Partly environment-concerned stakeholders (4)	-0.43**	0.60**	0.63**	1					
Logarithm of firm age (5)	-0.21**	0.11 †	0.16*	0.15*	1				
R&D intensity (6)	-0.29**	0.29*	0.18*	0.19*	0.09 †	1			
Number of employees (7)	-0.43**	0.26**	0.19**	0.32**	0.25**	0.21**	1		
Quality standard exists (8)	-0.32**	0.12 †	0.11 †	0.14*	0.04	0.06	0.18**	1	
Sole proprietorship (9)	0.21**	-0.12 †	-0.17**	-0.09	0.001	-0.13*	-0.04	-0.18**	1

† $p < .10$

* $p < .05$

** $p < .01$

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