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Determinants of Environmental Innovation – Theoretical Concepts and Empirical Evidence from Different Data Sources

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1 Introduction

This paper gives an overview of the main determinants of environmental innovation from a theoretical and especially empirical perspective. It is not the aim to present a new econometric model but to explore the main stylized facts based on the growing empirical literature on environmental innovation.

The paper is organised as follows: Section 2 departs from a definition of eco-innovation based on the results of a recent EU project on Measuring Eco-Innovation (MEI). In a second step, the main elements of an environmental innovation theory are summarized giving a basis for empirical analyses. Section 3 summarizes the main results of empirical environmental innovation analyses based on different data sources.
In Section 4 some propositions for the design of future empirical analyses of environmental innovation are developed.

2 Definition and theoretical background of eco-innovation

Empirical analyses of environmental innovation require a concise definition that can be translated in adequate survey questions or that can be used to define environmental related patents. Following the results of a recent EU project (MEI: Measuring Eco-Innovation) we define environmental innovation as “the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.” (Kemp and Pontoglio 2007:4)
This definition is very broad because it includes innovations that produce environmental gains as a gratis side-effect and innovations that explicitly aimed to reduce negative environmental effects. This is useful because especially the introduction of cleaner technologies is not always motivated by environmental reasons but by general economic considerations such as cost-savings (see e.g. Frondel, Horbach, Rennings 2007). Therefore, a concentration on only environmentally motivated eco-innovations would substantially underestimate the importance of environmental innovations.

On the basis of the OECD Guidelines for Collecting and Interpreting Technological Innovation Data (OECD and Eurostat 2005) environmental innovations can be classified as follows:

- *Process innovations* occur when a given amount of output (goods, services) can be produced with less input.
- *Product innovations* require improvements to existing goods (or services) or the development of new goods.
- *Organisational innovations* include new forms of management, e.g. total quality management.

The empirical analysis of environmental innovation can not be restricted to a simple identification of the different innovation activities of the questioned firms. Especially the development of political measures to promote environmental innovation requires a profound knowledge of the drivers and barriers and also, if possible, the economic and ecological impacts of eco-innovation. To derive empirical provable hypotheses and to define an adequate set of control variables it is necessary to look at the main results of environmental innovation theory. These theories are mainly based on explanations of general innovations, but there are also environmentally-specific determinants such as institutional and political factors. The general innovation theory stresses the relevance of technology push and market, or demand pull factors for the explanation of innovation activities (Hemmelskamp 1999). There is a consensus that technology push factors are especially important during the initial phase in developing a new product, whereas demand factors become more important during the diffusion phase (Rehfeld et al. 2007, Pavitt 1984). Most environmental problems represent negative external effects so that there is no clear economic incentive to develop new environmentally benign products and processes. Therefore, the general innovation theory has to be enlarged with respect to the analysis of the influence of environmental policy and institutional factors.

Table 1: Determinants of environmental innovation

Supply side	• Technological capabilities (R&D, internal and external knowledge, qualification of the staff, installed technology); • Appropriation problem and market characteristics • Technological opportunities (fitting time window) • Path dependencies
Demand side	• (Expected) market demand (demand pull hypothesis) • Social awareness of the need for clean production; environmental consciousness and preference for environmentally friendly products
Institutional and political influences	• Environmental policy (incentive based “flexible” instruments or regulatory approaches) • Institutional structure: e. g. political opportunities of environmentally oriented groups, organization of information flow, existence of innovation networks

Source: Horbach (in press).

Technology push (supply side)

In the general innovation theory, firm’s technological capabilities are emphasized (see e.g. Baumol 2002, Rosenberg 1974). These capabilities comprise the physical and knowledge capital stock of a firm to develop new products and processes. To build up such a capital stock inputs like R&D investment or further education of the employees are necessary.

Highly developed innovation capacities of a firm may lead to further innovation success in the future. Baumol characterizes these path dependencies appropriately by the expression “innovation breeds innovation” (Baumol 2002:284). In other words, the available technological possibilities (accumulation of human capital, available knowledge) induce further innovations. An innovation only makes sense for the firm if the innovator is able to capture the returns of his innovation activities. In fact “… the creator of an asset will typically fail to appropriate all or perhaps most of the social returns it generates.” (Jaffe et al. 2002:44). Therefore, the possibilities to minimize these so-called spill-overs are very important. These possibilities are dependent on technological characteristics (e.g. application of patents) and the market structure.

As Rödiger-Schluga (2005) pointed out, also variables like secrecy, lead time, technical complexity, learning curve effects or marketing advantages may serve as protection mechanisms.
Monopolistic market structures may help to overcome the appropriation problem, especially for large firms because they "… must fear less imitation from competitors and gain more from scale economies associated with innovations" (Smolny 2003:449). On the other hand, large monopolistic firms have less incentives to innovate, whereas small firms in competitive markets are forced to "be better" than their competitors by developing new products. As a result, the effect of the firm's size on its innovation activities is undetermined from a theoretical perspective.

A further important element of the success of environmental innovation coming from evolutionary economics consists in the concept of technological opportunities connecting the technological capabilities of a firm with the possibilities for commercial exploitation at any point of time (Rödiger-Schluga 2005). An innovation can only be successful if other factors and circumstances are fulfilled at the same time, in other words the innovation needs a fitting time window. If a process innovation emerges when the relevant branch has just invested in another technology it will probably not be used because of sunk costs.

Demand pull, business cycle

Especially in the diffusion phase of new (environmental) products the demand from consumers, public procurement, other firms and exports is relevant (Pavitt 1984). With regard to environmentally friendly products, the environmental consciousness of the consumers and the firms is an important variable.
There is increasing literature on the relationship between the business cycle and innovative activities (see e. g. Flaig and Stadler 1994, Geroski and Walters 1995, Smolny 2003) but the empirical analyses do not show a uniform picture. Also from a theoretical point of view, the relationship remains ambiguous. On the one hand, an increasing demand in the past and high capacity utilization indicate growing markets in the future, but on the other hand Smolny (2003:453) argues that in periods of slack demand "Non-production activities such as the reorganization of production processes, R&D and training exhibit less opportunity costs in case of excess capacities."

Environmental Policy

Because of negative external effects characterizing most environmental problems, environmental innovations are at least less market-driven than other innovations, therefore making environmental policy one of the main drivers of environmental innovation. The famous *Porter-hypothesis* (Porter and van der Linde 1995) postulates that environmental regulation may lead to a win-win situation so that pollution is reduced and profits are increased. The Porter-hypothesis is largely based on evolutional innovation theory. Because of large uncertainties concerning the success of R&D, this theory (Nelson and Winter 1982) says that firms use rules of thumb and routines with respect to their innovation behaviour. Hence, innovation activities are not a result of an optimization process. Following Porter and van der Linde, this argument is specifically relevant for the case of environmental innovation. Firms do not detect the potential of environmental innovations because they are "… still inexperienced in dealing creatively with environmental issues." Environmentally and economically benign innovations are not realized because of incomplete information, organizational and coordination problems (Porter and van der Linde 1995:99). Firms are not able to recognize the cost saving potentials (e.g. energy or material savings) of environmental innovation. Therefore, environmental regulation may "force" firms to realize economically benign environmental innovation. Furthermore, the encouragement of "soft" environmental measures like environmental accounting systems or eco-audits may improve the information basis for environmental innovation.

With respect to the technological opportunity problem, it is important that environmental policy may be easily anticipated by firms, so that they know their future time windows of opportunity for clean technologies.

3 Stylized facts from existing empirical analyses

The following section gives an overview of the main empirical analyses of the drivers of environmental innovation based on different data sources and methodologies. We will restrict on quantitative analyses based on patent and (panel-) survey data but it is important to mention the large literature dealing with case studies of environmental innovation (see e. g. Hemmelskamp et al. 2000).

Table 2: Data sources for the analysis of environmental innovation

Patent data, bibliometric data	• Identification of environmentally relevant patents, search for keywords in publications • Advantageous to explore the dynamic character of environmental innovation because of the existence of time series • Bias towards product innovation
(Panel-) Surveys	• Allow to include many different determinants and control variables • Lack of panel data so that dynamic analyses of eco-innovation based on this data source are very rare, one point in time surveys dominate the empirical literature
Official statistics	• Allow descriptive analyses of R&D on the sector level • Link between environmental innovations and their determinants seldom possible
Case studies	• Useful in addition to quantitative analysis e.g. to explore the history of a specific technology • Generalization of the results at least problematic

Source: See also Horbach 2005.

(Panel) Patent analyses:

The panel study of Brunnermeier and Cohen (2003) uses the number of successful environmental patent applications granted to US manufacturing industries between 1983 and 1992. As an indicator for environmental policy stringency, they apply pollution abatement expenditures and government monitoring activities. The authors find that increases in abatement expenditures were correlated with increases of environmental innovation but the effects were only small. There was no effect of monitoring activities on environmental innovation. Furthermore, the authors find a positive correlation between export intensity and innovation activities. They interpret export intensity as indicator for foreign demand for greener products. The influence of market structure measured by the four-firm concentration ratio remains undetermined when controlling for industry fixed effects.

Using cointegration techniques, Grupp (1999) detects positive effects of resource prices and environmental expenditures on environmental innovation measured by patent activities.

Jaffe and Palmer (1997) also apply a panel framework modelling R&D and patents as dependant variables. They find that higher abatement costs led to an increase of R&D expenditures but they do not detect a significant relationship between regulations and innovation output – a result that may be due to the weakness of compliance expenditures as a measure of regulatory stringency.

A recent analysis of de Vries and Withagen (2005) also uses environmentally related patents in Europe as environmental innovation indicators. They measure policy stringency according to three different indicators: Compliance with international agreements by individual signatories representing a more stringent domestic policy; an index of environmental sensitivity performance combining different pollutants, and furthermore, the authors modelled stringency as a latent variable: “Here the underlying idea is that high emission levels trigger strict environmental policy, which in turn provide an incentive for innovation.” (de Vries and Withagen 2005:28). Only for the third stringency indicator, the authors find a strong positive relationship with environmental innovation.

Wagner (2007) uses combined survey and patent data of German manufactoring firms to explore the link between environmental innovation, patents, and environmental management measures. He finds “…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.” (Wagner 2007:1). In his analysis, a combination of survey and patent data helps to avoid the problem of self-perception of environmental activities.

Recent (panel-) surveys

In the survey of Bartolomeo et al. (2003) the three most cited reasons for introducing an environmental innovation were to improve the firm’s image, to comply with environmental regulation and to reduce costs. The regulatory push/pull effect has also been confirmed by several other case studies and surveys (see e.g. Cleff and Rennings 1999).

Rennings et al. (2006) use survey data to analyze the influence of environmental management systems (especially EMAS) on environmentally related organizational, process and product innovations. Other than the positive influences of environmental management tools, the authors show that the existence of a specialized R&D department as an input variable triggers environmental innovation.

Rehfeld's et al. paper (2007) detects a positive relationship between the certification of environmental management systems and environmental product innovations for German manufacturing. Furthermore, waste disposal measures and product take-back systems are important drivers of environmental product innovations. The authors also find a positive influence of environmental policy, technology push and demand pull factors and the size of the firm on environmental product innovations.

Survey results for the determinants of the introduction of environmental R&D and cleaner technologies are available from a recent OECD project in 2003 on public environmental policy and the private firm covering seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway, and the USA) (see Arimura et al. 2007; Frondel et al. 2007; Johnstone 2007). The whole data set includes 4,186 observations originating from manufacturing facilities with more than 50 employees. 3,100 of the sample facilities, that is around 74%, took significant technical measures to reduce the environmental impacts associated with their activities (Frondel et al. 2007). Econometric results exploiting the OECD database show that a strict environmental policy measured by the perceived policy stringency of the questioned firm, environmental accounting systems and flexible environmental instruments stimulate environmental R&D. Environmental management tools and the possibility of cost savings are very important for the introduction of cleaner technologies (Frondel et al. 2007) but not for end-of-pipe measures.

Also based on the OECD data, Lanoie et al. (2007) test three versions of the Porter hypothesis following the interpretation of Jaffe, Palmer (1997): The weak version postulates that environmental regulation stimulates certain kinds of environmental innovation but it is not clear if it is socially beneficial. The narrow version presumes that flexible environmental instruments give firms greater incentives to innovate than prescriptive regulations. In the strong version regulation induces innovation "…that more than compensate for the cost of compliance" (Lanoie et al. 2007:3). The authors find strong support for the weak version and qualified support for the two other versions of the Porter hypothesis.

Using a panel data set of Italian firms in 2002 and 2004, Mazzanti and Zoboli (2006) stress the positive influence of network activities and R&D as an input of environmental innovation. The authors regard the influence of firm structural variables, environmental R&D, environmental policy pressure and regulatory costs, past firm performances, networking activities, other non environmental techno-organizational innovations and the quality and nature of industrial relations on eco-innovation. The results show that "… structural characteristics of the firm and performances appear to matter less than R&D, induced costs, networking, organisational flatness and innovative oriented industrial relations. Environmental policies and environmental voluntary auditing schemes exert some relevant direct and indirect effects on innovation, although evidence is mixed and further research is particularly needed." (Mazzanti and Zoboli 2006:2).

Horbach (in press) uses two German panel data bases, the establishment panel of the Institute for Employment Research (IAB) and the Mannheim Innovation Panel (MIP) of the Centre for European Economic Research (ZEW), to explore the determinants of environmental innovations. The econometric estimations show that the improvement of the technological capabilities ("knowledge capital") by R&D triggers environmental innovations. Environmental regulation, environmental management tools and general organizational changes also encourage environmental innovation, a result that has also been postulated by the famous Porter-hypothesis. The hypothesis that "innovation breeds innovation" is confirmed by the econometric results. General and environmental innovative firms in the past are also more likely to innovate in the present. The demand pull hypothesis is confirmed by both data bases.

Del Rio Gonzalez (2005) analyse the drivers of adopting cleaner technology in the Spanish pulp and paper industry. He found that most of the environmental technologies introduced were of the EOP type (i.e. waste water treatment plants) or incremental clean technologies. Regulatory pressure and corporate image were the main drivers for adopting green technologies. In contradiction to other survey results where cost savings are one of the main drivers of cleaner technologies (e.g. the OECD survey), costs are often seen as an obstacle, especially for firms that do not develop innovations themselves but have to buy them from suppliers.

4 Data requirements for future analyses

In the following, we try to develop an optimal set of relevant variables and preferable methodologies allowing the analysis of eco-innovation by econometric methods.

(Eco-) Innovation questions

Following our definition, all innovations that include an environmental benefit (broadly defined) have to be analyzed. In fact, not all environmentally-beneficial innovations are developed intentionally. Results of the IMPRESS survey show that 34.4% of the 1,594 most environmentally beneficial innovations were not introduced to comply with environmental regulations (Arundel 2005).
Concerning environmental innovation surveys and surveys in general, space in questionnaires is very limited, so that the classification of eco-innovation must be limited to only few categories. Hence, it is useful to follow the slightly revised Oslo manual definition dividing between process-, product- and organisational innovations.
With respect to patent or bibliometric analyses a much more detailed classification to derive the required keywords for the identification of environmental innovations may be used.

Drivers, barriers and impacts of eco-innovation, control variables

Based on the theoretical considerations in Section 2 the following set of determinants, impacts and control variables seem to be necessary for the design of empirical environmental innovation analyses (the lists are not comprehensive and only contain a core set of variables):

Determinants (drivers and barriers) of eco-innovation

- Inputs: financial and human resources, R&D expenditure supporting the technological capabilities of a firm;
- Environmental policy framework (e.g. regulatory stringency, different environmental policy instruments such as technology-based standards, emission taxes or liability for environmental damages);
- Existence of environmental management systems, practices and tools;
- Demand pull hypothesis: expected market demand, profit situation in the past;

- Appropriation problem: Competition situation (e.g. number of competitors, concentration of the market), innovation cooperation;
- Influence of stakeholders and motivations for environmental innovation (e.g. public authorities, pressure groups such as industry or trade associations);
- Availability of risk capital;
- Availability of high-skilled labour force.

Control variables and impacts

- Firm-level attributes (sector, size, stock market listing, employment, value of shipments);
- Commercial conditions (scope of the firms´ markets, competition, sales, profitability);
- Environmental impacts of the facilities´ products and production processes by different environmental fields (importance of each impact and change in impacts during the last three years).

Concerning the measurement level of both innovation and control variables, a general answer is not possible. For econometric analysis it would always be the best solution to analyze interval data but in many cases the firms are not able to provide quantitative answers on questions like “R&D expenditures for eco-innovation in EUR”. The number of missing values for these questions will be very high so that the results of econometric analyses would probably be biased. Therefore, questions that are likely to demand too much information of the interviewed firm representative have to be posed in a simple, in many cases, binary manner (see also Arundel 2005). Arundel (2005) proposes to obtain nominal data on prevalence of different types of innovation, ordinal data on inputs, outputs and impacts.

5 Summary

Following the results of a recent EU project on Measuring Eco-Innovation (MEI) environmental innovation may be defined as “the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.” This definition is very broad because it includes innovations that produce environmental gains as a gratis side-effect and innovations that explicitly aimed to reduce negative environmental effects.

Theoretical explanations of environmental innovations are mainly based on theories of general innovations, but there are also environmentally-specific determinants such as institutional and political factors. The general innovation theory stresses the relevance of technology push and market, or demand pull factors for the explanation of innovation activities. There is a consensus that technology push factors are especially important during the initial phase in developing a new product, whereas demand factors become more important during the diffusion phase. Most environmental problems represent negative external effects so that there is no clear economic incentive to develop new environmentally benign products and processes. Therefore, the general innovation theory has to be enlarged with respect to the analysis of the influence of environmental policy and institutional factors.

Empirical analyses mainly originating from patent and survey data confirm the important role of environmental policy, especially flexible instruments, for environmental innovation – a result that can be interpreted as support for the Porter hypothesis. Soft environmental policy measures such as the introduction of environmental management systems also promote environmental innovations. They reduce the information deficits to detect cost saving potentials (specifically material and energy savings) that are also an important driving force of environmental innovation.

Further important drivers of environmental innovation are resource prices, the improvement of a firms´ image, network activities and input factors like R&D expenditures and the qualification of a firms´ staff.

In line with theoretical considerations, the effect of the size of the firms and the influence of different market characteristics do not show a uniform picture.

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