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Determinants of Environmental Innovations in Germany: Do Organizational Measures Matter?

A Discrete Choice Analysis at the Firm Level

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Non-Technical Summary

This paper provides new empirical evidence regarding the determinants of different types of environmental technological innovations. Such innovations receive increasing attention from policy makers and scholars since they are expected to produce a double dividend, i.e. limit environmental burden and contribute to the technological modernization of the economy. However, an important peculiarity of environmental innovations is the so-called double externality problem. Environmental innovations produce not only the common spillovers of innovations in general, but they also create less environmental external costs. While the whole society benefits from an environmental innovation, the costs have to be borne by a single firm. Even if an environmental innovation can be successfully marketed, it is difficult for the company to appropriate the profits of this innovation if the corresponding knowledge is easily accessible for imitators and the environmental benefits have a public good character. As a consequence, the double externality problem leads to an increasing importance of regulatory framework since both externalities result in a suboptimal investment in environmental innovations.

Based on a unique firm level data set of the German manufacturing sector, we analyze particularly the effects of self-regulated environmental organizational measures on environmental innovations. These organizational measures play a central role in the discussion of so-called soft environmental policy instruments. It is argued that international initiatives concerning the certification for environmental management systems (EMS) such as the world-wide ISO 14001 standard or the European EMAS standard (besides other initiatives concerning the encouragement of firms to participate in voluntary pollution prevention programs) may be either a substitution or a supplement for traditional command and control regulation. They are expected to be able to promote both environmental product and process innovations. The econometric analysis in this paper is based on binary and multinomial discrete choice models. Simple multinomial logit and flexible multinomial probit models are considered because they allow for the examination of the determinants of specific types of environmental innovations compared with the absence of such innovations as basic alternative.

The most important result is that single measures such as product design with life cycle analysis and take back systems for products have a significantly strong positive effect on environmental product and process innovations. In contrast, the effects of certified EMS are statistically less reliable. While the ISO 14001 standard has a significantly weak positive influence, the EMAS standard has no significant effect on environmental innovations at all. A certification with at least one of these standards has a significantly positive effect on both the realization of an environmental product and a process innovation. However, this influence only holds true compared with the realization of no environmental innovation. Thus, some specific environmental organizational measures obviously may still stimulate environmental innovations to a larger extent than entire EMS. This means that the contribution of such programs to environmental technological innovation is not completely clear. Besides these environmental organizational measures, R&D activities have a significantly strong positive effect on both environmental product and process innovations. Thus, these technological opportunities may also stimulate environmental innovations as it has been recognized in industrial economics concerning innovations in general. This partly holds true for other well known variables included in this literature such as market pull factors. In contrast, neither the financial situation nor the skill structure have a significant effect on any type of environmental innovations.

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Determinants of Environmental Innovations in Germany: Do Organizational Measures Matter? A Discrete Choice Analysis at the Firm Level

Abstract

Based on a unique firm level data set of the German manufacturing sector, this paper provides new empirical evidence regarding the determinants of different types of environmental technological innovations. We examine particularly the effects of environmental organizational measures such as certified environmental management systems. The econometric analysis is based on binary and multinomial discrete choice models. The latter are considered because they allow for the examination of the determinants of specific types of environmental innovations compared with the absence of such innovations as basic alternative. The most important result is that single measures such as product design with life cycle analysis and take back systems for products have a significantly strong positive effect on environmental product and process innovations. In contrast, the effects of certified environmental management systems are statistically less reliable. While the world-wide ISO 14001 standard has a significantly weak positive influence, the European EMAS standard has no significant effect on environmental innovations at all. A certification with at least one of these standards has a significantly positive effect on both the realization of an environmental product and a process innovation, indeed only compared with the realization of no environmental innovation.

Keywords: Environmental Innovations, Environmental Organizational Measures, Discrete Choice Models, Sustainability.

JEL Classifications: Q55, O32, C25, Q01.

1 Introduction

Since the world community committed itself in 1992 in the Rio Declaration on Environment and Development to the principles of sustainable development, it has become more and more clear that sustainability means long-term and far-reaching changes of technologies. The demand for radical limitations of environmental burden e.g. of greenhouse gases implies that adaptation within existing technologies is not sufficient. Instead, regulation strategies to effect technology forcing and/or technological regime shifts have been introduced. This means that sustainable development needs a specific new type of innovations. This kind of innovations has been recently introduced into environmental economics and has been defined as environmental innovation (or eco-innovation, see Rennings, 2000). As a consequence, such environmental innovations receive increasing attention from policy makers and scholars since they are expected to produce a double dividend, i.e. limit environmental burden and contribute to the technological modernization of the economy (see Jaffe et al., 2002). Therefore, this paper examines the determinants of various types of this kind of innovations as a measure of environmental performance.

In doing so, this paper contributes to the environmental economics literature in several ways. Instead of considering the determinants of environmental organizational measures or examining other proxies for environmental performance such as toxic chemicals according to the Toxic Release Inventory (TRI) in the U.S. or environmental regulatory compliance, we analyze particularly the effects of such organizational measures on environmental technological innovations. Furthermore, this study includes some insights from industrial economics. On the one hand, these refer to determinants of innovations in general and on the other hand, to indicators for innovations, i.e. we do not utilize patents as a proxy for innovations.

Finally, this paper econometrically analyzes data at the firm level of the German manufacturing sector. Since these data allow to distinguish between environmental product and process innovations, we do not only examine the determinants of environmental innovations in general. This is the reason why the econometric analysis is not only based on binary, but also on multinomial discrete choice models. Such simple multinomial logit and flexible multinomial probit models allow for the examination of the determinants of specific types of environmental innovations compared with the absence of environmental innovations as basic alternative.

The paper is organized as follows: In the second section, the related environmental and industrial economics literature is reviewed. The third section explains the utilized dependent and explanatory variables for the discrete choice analysis. The fourth section provides some details concerning the data set. In the fifth section, the estimation results are discussed. The final section draws some conclusions.

2 Literature Background

The conventional understanding of innovations as defined in the Oslo-Manual of the OECD (1997) distinguishes mainly between product and process (as well as organizational) innovations in general. Environmental product and process innovations as specific kind of innovations consist of new or modified products and processes to avoid or reduce environmental harms (see e.g. Rennings and Zwick, 2002). An important peculiarity of environmental innovations is the so-called double externality problem (see Rennings, 2000). Environmental innovations produce not only the common spillovers of innovations in general, but they also create less environmental external costs (see e.g. Carraro, 2000, Jaffe et al., 2002). While the whole society benefits from an environmental innovation, the costs have to be borne by a single firm. Even if an environmental innovation can be successfully marketed, it is difficult for the company to appropriate the profits of this innovation if the corresponding knowledge is easily accessible for imitators and the environmental benefits have a public good character. As a consequence, the double externality problem leads to an increasing importance of regulatory framework since both externalities result in a suboptimal investment in environmental innovations.

In this study, we analyze particularly the effects of self-regulated environmental organizational measures of a company on different environmental innovations. Such measures play a central role in the discussion of so-called soft environmental policy instruments. It is argued that e.g. initiatives concerning the encouragement of firms to participate in voluntary pollution prevention programs such as 33/50 or Green Lights, which are both initiated by the U.S. Environmental Protection Agency (EPA), may be either a substitution or a supplement for traditional command and control regulation (see e.g. Arora and Cason, 1995, Khanna and Damon, 1999). Two other important international initiatives are the certifications for environmental management systems (EMS), i.e. the world-wide ISO 14001 standard (published by the International Organization for Standardization) and the European EMAS (EU Environmental Management and Auditing Scheme) standard. Regarding particularly these certifications, it is argued that they are able to promote both environmental product and process innovations. Based on a survey of EMAS certified facilities in Germany, this view has been supported by the appraisal of EMAS or environmental managers of these facilities (see Rennings et al., 2003). Note that our unique firm level data set of the German manufacturing sector includes information on these two certifications, but beyond also on other environmental organizational measures.

Our econometric analysis of the effects of several environmental organizational measures on environmental innovations differs from other econometric studies at the firm level that rather examine the determinants of such measures. For example, based on a binary probit analysis, Nakamura et al. (2001) consider the determinants of ISO 14001 certifications. In addition, they examine the determinants of environmental management measures beyond the ISO 14001 certification. Econometric analyses of the determinants of environmental organizational measures can also be found in Arora and Cason (1995) explaining the participation in the 33/50 program, in Henriques and Sadorsky (1996) explaining the formulation of an environmental plan, in DeCanio and Watkins (1998) explaining the participation in the Green Lights program, or in Khanna and Anton (2002) explaining the comprehensiveness of EMS. Note that programs such as 33/50 or Green Lights (initiated by EPA) do not imply any penalties for withdrawal at any time. But regarding the environmental behavior of companies, the examination of environmental organizational measures such as the participation in non-binding environmental plans (even if there are clear targets to limit environmental burden such as e.g. in the 33/50 program for toxic releases) does not seem to be sufficient. In other words, such measures do not guarantee any improvement in environmental performance (see e.g. Dasgupta et al., 2000, Anton et al., 2004). Thus, it seems to be important to analyze the effects of environmental organizational measures on broader proxies for environmental performance (see e.g. Nakamura et al., 2001).

Studies regarding the influence of such measures on far-reaching indicators for environmental performance can e.g. be found in Khanna and Damon (1999), Dasgupta et al. (2000), or Anton et al. (2004). All three studies are based on two-stage econometric approaches. In this framework, they also examine (like the studies aforementioned) the determinants of environmental organizational measures in the first stage. In the second stage, Dasgupta et al. (2000) analyze the influence of four different environmental management (including ISO 14001-type) variables on self-assessed compliance with environmental regulations. In contrast, Khanna and Damon (1999) examine the effect of the participation in the 33/50 program and Anton et al. (2004) the effect of the comprehensiveness of some environmental management practices on toxic releases. All three studies show a significantly positive influence of some environmental organizational measures on environmental performance. Concerning the inclusion of such measures as determinants of environmental performance, our study has some analogies to these analyses. But there are also important conceptual differences e.g. concerning the utilized econometric methodology or the inclusion of other explanatory variables as discussed below. But most notably, we utilize environmental product and process innovations as indicators for environmental performance instead of the use of narrower proxies such as toxic chemicals according to the TRI or self-assessed environmental regulatory compliance.

Jaffe and Palmer (1997) examine the effect of environmental regulatory compliance expenditures on innovation activities. However, note that they consider innovation activities in general, i.e. not specifically environmental activities. To our knowledge, the only econometric analyses of the determinants of environmental innovations can be found in Cleff and Rennings (1999), Rennings et al. (2003), and Brunnermeier and Cohen (2003). But in contrast to our study, the former two studies include restricted samples of companies (Cleff and Rennings, 1999, only utilize data of companies that have realized environmental product, process, and/or organizational innovations, Rennings et al., 2003, only utilize data of EMAS certified facilities) so that the conclusions concerning the determinants of environmental innovations are extremely limited. Brunnermeier and Cohen (2003) do not consider the effects of environmental organizational measures in general and certifications for EMS in particular.

Furthermore, they measure environmental innovations by the number of successful environmental patent applications. But it should be noted that according to industrial economics (see e.g. Gottschalk and Janz, 2003), patents (which are also utilized in Jaffe and Palmer, 1997) are a bad indicator for innovations. Patents rather refer to inventions which are placed at the beginning of the total innovation process and which need not lead to (product or process) innovations. Therefore, we do not utilize patents as a proxy for innovation. Instead, we consider the end of the total innovation process and thus apply the innovation definition according to the Oslo-Manual of the OECD (1997). But most notably, Brunnermeier and Cohen (2003) only utilize aggregated data at the industry level. Thus, they are not able to analyze the firm-specific determinants of environmental innovations so that the conclusions based on their analysis are also limited. In contrast, our analysis is based on disaggregated data at the firm level.

This paper takes into account some insights from industrial economics, i.e. we consider some variables that may influence innovations in general and include them as control variables in the econometric analysis to explain environmental innovations as specific kind of innovations. According to this literature (see e.g. Ebling and Janz, 1999, Gottschalk and Janz, 2003), one important determinant of innovations is the so-called demand pull, i.e. it is argued that innovative activities are substantially determined by the market (see also Pavitt, 1984, Harabi, 1997). Another determinant is technological opportunities, i.e. the universe of usable firm-external innovation resources. In this respect, the extent of the adoption of technological opportunities depends on the absorption ability of the companies. Furthermore, exports may have a positive effect on innovations because the opening of foreign markets can increase innovation rents. An important determinant of innovations is also the firm size. In this respect, often a U-shaped relationship between size and innovation arises. Finally, the financial situation and the skill structure of the company seem to be very important (see also Czarnitzki, 2002). It is argued that innovative companies need financial resources and highly qualified employees.

We utilize discrete choice models for the econometric analysis of the discussed issue. Since our data include information on environmental product and process innovations, we do not only estimate the determinants of environmental innovations in general. This is the reason why we also consider multinomial besides binary discrete choice models. In the framework of binary probit or logit models (see e.g. Greene, 2000) e.g. for the explanation of environmental product innovations, the basic alternative comprises companies that do not realize environmental product innovations. But this alternative also comprises companies that do realize environmental process innovations. Thus, binary discrete choice models do not have the ability to analyze the determinants of specific types of environmental innovations compared with the absence of environmental innovations as basic alternative. In the framework of the considered three-alternative and four-alternative discrete choice models, the estimation results in the simple multinomial logit model (see McFadden, 1973) and in the flexible multinomial probit model (see e.g. Börsch-Supan and Hajivassiliou, 1993) are compared. Note that the estimation of multinomial probit models needs the application of simulation methods due to the underlying multiple integrals (see also e.g. Geweke et al., 1994, Keane, 1994).

3 Models and variables

The data of the underlying telephone survey distinguish between environmental product and process innovations. Concerning environmental product innovations, the companies have been questioned whether they have introduced an environmentally improved product or a new environmentally friendly product to the market within the precedent three years. Concerning environmental process innovations, the companies have been asked whether they have carried out a more environmentally friendly composition of one or more firm-internal processes in this period (independent of the realization of environmental product innovations). Furthermore, the companies have also been questioned whether they plan to realize such environmental product or process innovations by the end of 2005, independent from any innovative activity in the past. Note that the past environmental innovations are not utilized in the econometric analysis because e.g. environmental organizational measures may depend on environmental innovations which makes these explanatory variables endogenous. By including explanatory variables surveyed for the past and future environmental innovations as dependent variables or, in other words, by examining lagged explanatory variables, this econometric problem can be reduced if not avoided (see also Arora and Cason, 1995).

In the first step, a binary discrete choice analysis is performed. On the one hand, the determinants of environmental product innovations and the determinants of environmental process innovations are examined. Concerning the dependent dummy variables, the main alternative of "**Product-Inno**" comprises companies that will realize an environmental product innovation and the main alternative of "**Process-Inno**" comprises companies that will realize an environmental process innovation. On the other hand, we also construct combined variables of environmental innovative measures. The main alternative of "**Product-Or-Process-Inno**" in the corresponding binary discrete choice model contains firms that will realize an environmental product or a process innovation and the main alternative of "**Product-And-Process-Inno**" contains firms that will realize both an environmental product and a process innovation. In the framework of these different binary discrete choice models, we assume that a company i ($i = 1, \ldots, N$) will realize a specific type of environmental innovation if the expected profit from realization is greater than the expected profit from not realizing. The underlying latent variables for i have the following appearance:

$$U_i = \beta' x_i + \varepsilon_i$$

The vectors of the K known explanatory variables discussed below are $x_i = (x_{i1}, \ldots, x_{iK})$ and the corresponding unknown parameter vector is $\beta = (\beta_1, \ldots, \beta_K)'$. Since we consider binary probit models, the stochastic components ε_i are standard normally distributed. Note that the latent variables U_i are not observable. Observable is only the decision of a firm concerning the realization of a specific environmental innovation. As a consequence, the probabilities of the realization of such an innovation are incorporated into the likelihood function for the maximum likelihood estimation of the models (see e.g. Greene, 2000).

Indeed, it should be noted that in the framework of binary discrete choice models, the basic alternatives of the dependent variables "Product-Inno", "Process-Inno", or "Product-And-Process-Inno" contain companies that will not realize environmental innovations as well as companies that will realize environmental innovations. For example, the basic alternative of "Product-And-Process-Inno" also contains companies that will realize an environmental product or a process innovation, but not both types together. Therefore, a binary probit analysis cannot examine the determinants of specific types of environmental innovations compared with the absence of environmental innovations. However, such an analysis is possible with multinomial discrete choice models by constructing suitable mutually exclusive alternatives. In this paper, three-alternative and four-alternative logit and probit models are considered. With j ($j = 1, 2, 3$ or $j = 1, 2, 3, 4$) as a specific type of environmental innovations in the multinomial discrete choice models, we assume that a company i will realize that type j that guarantees the highest expected profit. The underlying (unobservable) latent variables for firm i and alternative j have the following appearance:

$$U_{ij} = \beta_j' x_i + \varepsilon_{ij}$$

The vectors $x_i = (x_{i1}, \ldots, x_{iK})$ again comprise the K known explanatory variables discussed below. The corresponding unknown parameter vectors are $\beta_j = (\beta_{j1}, \ldots, \beta_{jK})'$. For the formal identification of the multinomial discrete choice models, the parameter vectors β_3 in the three-alternative and β_4 in the four-alternative case are restricted to zero.

The three-alternative discrete choice models include the alternatives "**Product-And-Process-Inno**" ($j = 1$) and "**Either-Product-Or-Process-Inno**" ($j = 2$). The first alternative comprises companies that will realize both an environmental product and a process innovation, the second alternative contains companies that will realize an environmental product or a process innovation, but not both types together. The basic alternative "**No-Inno**" ($j = 3$) comprises companies that will neither realize an environmental product nor a process innovation. The four-alternative discrete choice models include the alternatives "**Product-And-Process-Inno**" ($j = 1$), "**Only-Product-Inno**" ($j = 2$), "**Only-Process-Inno**" ($j = 3$), and as the basic alternative "**No-Inno**" ($j = 4$). The alternatives "Product-And-Process-Inno" and "No-Inno" are the same as in the three-alternative discrete choice models. "Only-Product-Inno" comprises companies that will realize an environmental product, but not an environmental process innovation, "Only-Process-Inno" contains companies with converse property concerning both types of environmental innovations. Note that by fragmenting "Either-Product-Or-Process-Inno" in the three-alternative discrete choice models in "Only-Product-Inno" and "Only-Process-Inno" in the four-alternative discrete choice models, some deeper insights into the determinants of both types of environmental innovations can be gained.

If we assume that the stochastic components ε_{ij} are independently and identically distributed with Type I extreme value density functions, we obtain the popular multinomial logit models (see McFadden, 1973). Since the probabilities of the realization of an alternative j have a simple structure, these multinomial discrete choice models can be estimated by the maximum likelihood method implemented in standard software packages. Indeed, these models have the restrictive independence of irrelevant alternatives (IIA) property. This property implies that the choice between two alternatives is independent from the existence of other alternatives. This property can be very limiting in the examination of the determinants of environmental innovations. Particularly in the four-alternative discrete choice case, it seems to be very unrealistic to assume that no relationship between the alternatives exists. Such correlations can be included in multinomial probit models (see e.g. Börsch-Supan and Hajivassiliou, 1993). One obtains these models if

$$(\varepsilon_{i1}, \varepsilon_{i2}, \varepsilon_{i3})' \sim \mathrm{N}_3(0; \Sigma_3) \quad \text{or} \quad (\varepsilon_{i1}, \varepsilon_{i2}, \varepsilon_{i3}, \varepsilon_{i4})' \sim \mathrm{N}_4(0; \Sigma_4)$$

in the three-alternative or four-alternative case. Correlations between the alternatives of the dependent variable can be modelled in the variance covariance matrices Σ_3 or Σ_4 of the ε_{ij}. The corresponding (formally identifiable) variance covariance parameters (two in the three-alternative and five in the four-alternative probit model, for details see Ziegler, 2001) are estimated together with the parameters of the explanatory variables. The practical disadvantage of flexible multinomial probit models is that the resulting probabilities of the realization of an alternative j are characterized by multiple integrals, Therefore, the application of simulation methods in the framework of the maximum likelihood estimation is necessary (see also e.g. Geweke et al., 1994) and thus standard software packages cannot be utilized.

The first major group of explanatory variables for environmental innovations considered in the discrete choice analysis comprises environmental organizational measures. As aforementioned, it is argued that such organizational or management measures may be the basis for extensive environmental technological measures (see e.g. Rennings et al., 2003). Due to the importance in the political debate, particularly the effect of the certification for EMS according to the ISO 14001 and EMAS standard is analyzed. The dummy variables "$\mathbf{ISO14001}_i$" or "$\mathbf{EMAS}_i$" take the value one if at least one facility of a company i is presently (in 2003) certified according to ISO 14001 or EMAS.

Beyond these certifications for EMS, we also examine the effects of some single environmental organizational or management measures. The dummy variables "$\mathbf{Lifecycle}_i$" or "$\mathbf{Disposal}_i$" take the value one if i presently evaluates products by means of life cycle considerations or if the company presently performs measures concerning disposal or withdrawal of products. Note that we have also experimented with the inclusion of one more environmental organizational measure, namely the present existence of suppliers audits. However, it has been shown that this measure has never had a significant effect on any type of environmental innovations and therefore we do not consider this factor in the following. Finally, we also include another certified non-environmental organizational measure, namely the certification for the quality management system ISO 9001. This inclusion is of relevance because it is possible that environmental innovations are not only caused by far-reaching specific environmental management measures, but also by far-reaching management measures in general. The corresponding dummy variable "$\mathbf{ISO9001}_i$" takes the value one if one or more facilities of i are presently certified according to ISO 9001.

As aforementioned, this study incorporates some insights from industrial economics concerning the determinants of innovations in general. As market pull factors, we consider three different variables. The dummy variables "**Comp-Pressure**$_i$", "**Comp-Factor-Client**$_i$", or "**Comp-Factor-Environment**$_i$" take the value one if a company i states that the pressure of competition on the most important sales market has increased within the precedent three years (from the beginning of 2001 until 2003), if it states that customer satisfaction is an important factor to deliver competitive advantages on the most important sales market, or if it states that environmental issues are similarly an important factor to deliver competitive advantages on this market (in each case within the precedent three years). Note that we have also experimented with two more market pull factors, namely the appraisal that prices or quality are an important factor to deliver competitive advantages on the most important sales market. The result has been that none of both variables has ever had a significant effect on the different types of environmental innovations. Therefore, we do not consider these variables below.

One indicator for absorption ability of companies regarding technological opportunities is the existence of an R&D department. We have also experimented with an according dummy variable, but this factor has never had a significant influence on any type of environmental innovations and is therefore excluded from the following analysis. Instead, a variable concerning R&D activities in general is considered. The corresponding dummy variable "**R&D**$_i$" takes the value one if a company i has carried out R&D activities in the precedent year (2002). Concerning the potential positive effect of exports on innovations, we consider the corresponding dummy variable "**Exports**$_i$" that takes the value one if i has exported in the precedent year. Regarding firm size, we have experimented with different variables concerning the number of salaried employees. The result has been that the inclusion of the pure unsquared and/or squared firm size as well as the inclusion of the unsquared logarithm of the firm size do not have the explanatory power of the inclusion of only the squared logarithm of the firm size. Therefore, only the corresponding variable "**Ln-Employees-Squared**$_i$" that indicates the squared logarithm of the number of salaried employees (divided by 100 due to dimensionality) of i at the end of the precedent year is considered in the following.

We have also analyzed the financial situation and the skill structure of the company as determinants. As an indicator for the financial situation, we have experimented with the present firm value evaluated by "Creditreform", the largest German credit rating agency, and as an indicator for skill structure, we have experimented with the ratio between the number of salaried employees with a university or college degree and the number of all salaried employees at the end of the precedent year. The analysis has shown that none of these variables has ever had a significant effect on the different types of environmental innovations and therefore we do not consider these variables below.

In contrast, two other firm-specific control variables are examined, namely the present firm age (i.e. the years since foundation or since the last organizational modification, i.e. fusion or splitting) and the present number of facilities. Concerning the former factor, we have experimented with several specifications. Due to the highest explanatory power, the variables "**Reciprocal-Age**$_i$" and "**Reciprocal-Age-Squared**$_i$" that indicate the reciprocal of the age of firm i and the squared reciprocal of the age of i (in each case multiplied by ten due to dimensionality) are considered in the following. Concerning the latter factor, the dummy variable "**One-Facility**$_i$" that takes the value one if a company i consists only of one facility is examined. Finally, we also include eight industry dummies and one regional dummy (for Western Germany excluding Berlin) for potential industry and regional influences on environmental innovations e.g. concerning differences in environmental policy or in market concentration. Note that the industry and regional dummies are utilized in all estimations, albeit the estimates of the corresponding parameters are not displayed below for brevity. Altogether, we can now specify the vectors $x_i = (x_{i1}, \ldots, x_{iK})$ (with $K = 24$) of the explanatory variables as follows:

$$x_i = (\text{Constant}, \text{ISO14001}_i, \text{EMAS}_i, \text{Lifecycle}_i, \text{Disposal}_i, \text{ISO9001}_i, \text{Comp-Pressure}_i, \text{Comp-Factor-Client}_i, \text{Comp-Factor-Environment}_i, \text{R\&D}_i, \text{Exports}_i, \text{Ln-Employees-Squared}_i, \text{Reciprocal-Age}_i, \text{Reciprocal-Age-Squared}_i, \text{One-Facility}_i, \text{industry and regional dummies for } i)$$

In the following, the indices i are neglected in the analysis of the explanatory variables.

4 Data

The data for the discrete choice analysis is based on a telephone survey that has been conducted at the Centre for European Economic Research (ZEW) in Mannheim, Germany, from the middle of July 2003 until the end of November 2003. The population is the universe of all German manufacturing companies (NACE-Codes 15-37) with at least 50 employees. Based on the database of "Creditreform", 2998 addresses have been drawn from a stratified representative sample considering two firm size classes (less than 200 and at least 200 employees), two regions (Western and Eastern Germany), and eleven industries. The corresponding companies have been notified in advance of the forthcoming survey by mail. 2511 companies have been attempted to reach. Of these 2511 companies, 112 could not be reached, 1811 have refused to participate, and 588 have participated in the survey. Thus, of the 2399 reached companies, 24.5% have participated. The survey has been pre-tested for clarity and understandability with several companies that have also been notified in advance. The interviews have been conducted by interviewers with long standing experience in telephone surveys. The person responsible for production in the company has been the target person of the interviews. Note that all firm-specific questions and thus all variables discussed above refer to all facilities of a company in Germany. In contrast, the firm-specific information in the database of "Creditreform" e.g. concerning the number of employees refer to all world-wide facilities. As a consequence, our sample comprises some companies with less than 50 (salaried) employees.

Altogether, $N = 390$ of the 588 companies that have participated can be included in the econometric analysis. Note that besides the companies with missing data concerning the aforementioned variables, we exclude companies that have been founded or organizationally modified in the years 2002 or 2003 since many questions refer to the period from 2001 to 2003. With regard to the aforementioned two firm size classes, two regions, and eleven industries, it has been tested whether the corresponding shares for these $N = 390$ companies comply with the shares from the population. The appropriate two-tailed tests have shown that the underlying null hypotheses can never be rejected at the 10% level of significance. Regarding the dependent variables in the discrete choice analysis of the $N = 390$ companies, 146 (=37.4%) will realize an environmental product innovation, 256 (=65.6%) will realize an environmental process innovation, 283 (=72.6%) will realize an environmental product or a process innovation, 119 (=30.5%) will realize both an environmental product and a process innovation, 164 (=42.1%) will realize an environmental product or a process innovation, but not both types together, 137 (=35.1%) will realize an environmental process, but not a product innovation, 27 (=6.9%) will realize an environmental product, but not a process innovation, and 107 (=27.4%) will neither realize an environmental product nor a process

Table 1: Means of the explanatory variables ($N = 390$)

Explanatory variables	Mean
ISO14001	0.2333
EMAS	0.0744
Lifecycle	0.1615
Disposal	0.3718
ISO9001	0.6436
Comp-Pressure	0.7051
Comp-Factor-Client	0.9077
Comp-Factor-Environment	0.2051
R&D	0.7462
Exports	0.8385
Ln-Employees-Squared	0.2482
Reciprocal-Age	1.1762
Reciprocal-Age-Squared	0.3457
One-Facility	0.5385

innovation. Table 1 reports the means of the explanatory variables (excluding the industry and regional dummies).

The maximum likelihood estimations of the binary probit and multinomial logit models have been performed with the software package STATA. In doing so, the so-called robust estimations of the standard deviation of the parameter estimates (according to White, 1982, for details see the handbooks of STATA) to calculate the z-statistics are considered. The estimations of the multinomial probit models have been based on a self-developed GAUSS program. Note again that the estimation of flexible multinomial probit models needs the application of simulation methods because of the underlying multiple integrals. The applied GAUSS program utilizes the so-called GHK (Geweke-Hajivassiliou-Keane) simulator (see Börsch-Supan and Hajivassiliou, 1993, Geweke et al., 1994, Keane, 1994) in the framework of the maximum likelihood method. The number of random draws in the GHK simulator in the three-alternative and four-alternative probit models totals 50. Note that in the simulated maximum likelihood estimations of the multinomial probit models, the standard deviations of the parameter estimates to calculate the z-statistics have also been estimated robustly (by means of the GHK simulator, for details see Ziegler, 2001).

In the following, the effect of a variable is regarded as insignificant if the absolute value of the corresponding z-statistic is smaller than 1.65. Note that concerning the explanatory power of the discrete choice models at all, the null hypothesis that all parameters of the explanatory variables together are zero can be rejected at a level of significance that is clearly smaller than 5% in all binary probit, multinomial logit, and multinomial probit models. This hypothesis has been tested with the Wald and the likelihood ratio test (see e.g. Greene, 2000) in the binary probit and multinomial logit estimations as well as with the simple simulated counterpart of the likelihood ratio test in the multinomial probit estimations (for details regarding simulated classical tests in multinomial probit models see Ziegler, 2002).

5 Results

In the first step, the results of the binary probit estimations are analyzed. Concerning the variables from industrial economics and the other control variables, one finds according to Table 2 that R&D activities have a positive effect on all four measures of environmental innovations at the 5% level of significance. In contrast, the variables "Exports" and "One-Facility" never have a significant influence. The market pull factors "Comp-Pressure", "Comp-Factor-Client", and "Comp-Factor-Environment" have a strong positive effect on the realization of an environmental product innovation as well as on the realization of both an environmental product and a process innovation at the 5% level of significance. According to these results, it can be concluded that similar to innovations in general, environmental innovations and particularly environmental product innovations are also influenced by the absorption ability concerning technological opportunities and by market pull factors such as the pressure from the sales market and the customer satisfaction or environmental issues as important competition factors.

The firm size has a positive effect on the realization of an environmental product or a process innovation (compared with the realization of no environmental innovation) at the 5% level of significance, but it has no significant influence on "Product-And-Process-Inno". The effects on "Product-Inno" and "Process-Inno" are also positive, but less significant. Concerning the firm age, a significant effect on "Product-And-Process-Inno" does not arise, either. In contrast, "Reciprocal-Age" and "Reciprocal-Age-Squared" have a significant influence on "Product-Inno", "Process-Inno", and "Product-Or-Process-Inno" (for the latter even at the 5% level of significance). This means that there is obviously a U-shaped relationship between firm age and the probability of the realization of an environmental product innovation, an environmental process innovation, or an environmental product or a process innovation.

As aforementioned, the focus of the analysis is on the effects of environmental organizational measures. Table 2 shows that the estimates of the parameters of "ISO14001" and "EMAS" are positive in all four binary probit models. But a significant effect of the ISO

Table 2: Parameter estimates in the binary probit models

	Dependent variables			
Explanatory variables	Product-Inno	Process-Inno	Product-Or-Process-Inno	Product-And-Process-Inno
Constant	-2.0441** (-4.05)	-0.6902 (-1.38)	-1.1830** (-2.21)	-1.9793** (-3.76)
ISO14001	0.1421 (0.77)	0.3316 (1.62)	0.4370* (1.94)	0.1355 (0.71)
EMAS	0.2104 (0.76)	0.0556 (0.17)	0.0172 (0.05)	0.2450 (0.84)
Lifecycle	0.4065** (2.00)	0.4640** (1.96)	0.2391 (0.97)	0.6295** (3.13)
Disposal	0.4132** (2.76)	0.2102 (1.35)	0.4288** (2.57)	0.3270** (2.13)
ISO9001	0.0808 (0.48)	0.4040** (2.54)	0.2787* (1.66)	0.2435 (1.41)
Comp-Pressure	0.3274** (2.11)	-0.1497 (-0.95)	-0.1350 (-0.79)	0.3344** (2.11)
Comp-Factor-Client	0.5920** (2.00)	0.1979 (0.82)	0.3014 (1.18)	0.6412** (1.97)
Comp-Factor-Environment	0.6325** (3.76)	0.1039 (0.58)	0.3859* (1.90)	0.4637** (2.75)
R&D	0.4742** (2.38)	0.4332** (2.45)	0.5202** (2.80)	0.5353** (2.50)
Exports	0.2623 (1.06)	0.0381 (0.19)	0.2398 (1.11)	-0.0001 (-0.00)
Ln-Employees-Squared	1.3071* (1.67)	1.5121* (1.82)	2.6341** (2.91)	0.8884 (1.15)
Reciprocal-Age	-0.2989* (-1.65)	-0.2978* (-1.68)	-0.6462** (-3.35)	-0.1617 (-0.88)
Reciprocal-Age-Squared	0.8475** (2.26)	0.6616* (1.80)	1.6117** (3.66)	0.4872 (1.30)
One-Facility	0.0328 (0.21)	0.0640 (0.42)	0.1627 (1.01)	-0.0453 (-0.27)

Remarks:
All estimations include eight industry dummies and one regional dummy (for Western Germany).
Z-statistics in parentheses. * (**) means that the null hypothesis that the appropriate parameter is zero can be rejected at the 10% (5%) level of significance (according to the corresponding two-tailed test). $N = 390$.

14001 certification arises only with respect to the realization of an environmental product or a process innovation (compared with the realization of no environmental innovation), albeit the influence can only be verified at the 10% level of significance. Furthermore, the EMAS certification never has a significant effect on any type of environmental innovations. Concerning the other variables of environmental organizational measures, their influence is clearly stronger. The evaluation of products by means of life cycle considerations has a positive effect on "Product-Inno", "Process-Inno", and "Product-And-Process-Inno" at the 5% level of significance. Measures concerning the disposal or withdrawal of products have a positive influence on "Product-Inno", "Product-Or-Process-Inno", and "Product-And-Process-Inno" at the 5% level of significance. Finally, non-environmental organizational measures expressed by the ISO 9001 certification have a positive effect on the realization of an environmental process innovation at the 5% level of significance and a less significantly positive effect on "Product-Or-Process-Inno". Thus, organizational and particularly environmental organizational measures obviously have the potential to stimulate environmental innovations. But it should be emphasized that according to the binary probit analysis, specific environmental organizational measures seem to be more important than entire EMS in this respect.

Table 3 reports the estimation results in the aforementioned three-alternative and four-alternative logit models to get some deeper insights into the determinants of environmental innovations. Concerning the variables from industrial economics and the other control variables, there are some modifications compared with the estimation results in the binary probit models. For example, firm size and firm age have a strong effect on all alternatives in both multinomial logit models at the 5% level of significance. In this respect, a U-shaped relationship between firm age and the probability of the realization of any type of environmental innovations can again be identified. The market pull factors "Comp-Factor-Client" and

Table 3: Parameter estimates in the multinomial logit models

	Basic alternative: No-Inno				
	Three-alternative logit model		Four-alternative logit model		
Explanatory variables	Product-And-Process-Inno	Either-Product-Or-Process-Inno	Product-And-Process-Inno	Only-Product-Inno	Only-Process-Inno
Constant	-4.3019** (-3.58)	-2.2954** (-2.43)	-4.3372** (-3.61)	-6.8188** (-2.98)	-2.1875** (-2.27)
ISO14001	0.7828* (1.69)	0.7563* (1.77)	0.7825* (1.68)	0.6643 (0.92)	0.7747* (1.78)
EMAS	0.2393 (0.35)	-0.2888 (-0.45)	0.2423 (0.36)	-0.2378 (-0.21)	-0.2971 (-0.45)
Lifecycle	1.0151** (2.05)	-0.0589 (-0.11)	0.9739** (1.97)	-1.4504 (-1.19)	0.0859 (0.17)
Disposal	0.9974** (2.84)	0.6367** (2.02)	1.0180** (2.90)	1.1853** (2.21)	0.5319 (1.63)
ISO9001	0.6891* (1.87)	0.4041 (1.32)	0.6516* (1.77)	-0.1899 (-0.33)	0.5392* (1.69)
Comp-Pressure	0.2299 (0.65)	-0.4418 (-1.42)	0.2420 (0.69)	-0.0225 (-0.04)	-0.5314^* (-1.66)
Comp-Factor-Client	1.4005** (1.99)	0.2060 (0.48)	1.4341** (2.02)	0.4382 (0.50)	0.1617 (0.37)
Comp-Factor-Environment	1.0559** (2.70)	0.3443 (0.85)	1.0574** (2.70)	1.3401** (2.32)	0.0764 (0.18)
R&D	1.3667** (3.04)	0.6767** (2.01)	1.3493** (3.01)	0.8626 (1.35)	0.6582* (1.87)
Exports	0.2989 (0.57)	0.4335 (1.14)	0.3250 (0.61)	1.9165* (1.94)	0.2611 (0.67)
Ln-Employees-Squared	4.6262** (2.69)	4.5298** (2.66)	4.7116** (2.72)	5.9405** (2.13)	4.2337** (2.39)
Reciprocal-Age	-1.1108** (-2.66)	-1.0894** (-3.00)	-1.1329** (-2.69)	-1.7388** (-2.72)	-0.9621** (-2.58)
Reciprocal-Age-Squared	2.8895** (3.08)	2.6478** (3.09)	2.9568** (3.11)	4.3384** (3.44)	2.3005** (2.58)
One-Facility	0.1155 (0.33)	0.3105 (1.07)	0.1182 (0.34)	0.5720 (1.06)	0.2771 (0.92)

Remarks:
All estimations include eight industry dummies and one regional dummy (for Western Germany).
Z-statistics in parentheses. * (**) means that the null hypothesis that the appropriate parameter is zero can be rejected at the 10% (5%) level of significance (according to the corresponding two-tailed test). $N = 390$.

"Comp-Factor-Environment" have a positive effect on "Product-And-Process-Inno" in both multinomial logit models and "Comp-Factor-Environment" additionally on "Only-Product-Inno" in the four-alternative logit model at the 5% level of significance. Thus, it seems that customer satisfaction and environmental issues as an important competition factor also stimulate both environmental product and process innovations together. Furthermore, environmental issues as an important competition factor additionally have a specific strong effect on environmental product innovations.

The strongest difference between the estimation results in the binary probit and multinomial logit models refers to the variable "Comp-Pressure" since it has no significant effect on "Product-And-Process-Inno" in both multinomial logit models and even a negative effect on "Only-Process-Inno" in the four-alternative logit model at the 10% level of significance. Thus, it seems that this factor is not a decisive stimulator for environmental innovations. Concerning the three remaining variables, the estimation results in the binary probit models are largely verified. "One-Facility" never has a significant influence and "Exports" only has a positive effect on "Only-Product-Inno" in the four-alternative logit model at the 10% level of significance. In contrast, R&D activities strongly stimulate both environmental product and process innovations as it is shown in the binary probit analysis. The corresponding variable has a positive effect on "Product-And-Process-Inno" in both multinomial logit models and on "Either-Product-Or-Process-Inno" in the three-alternative logit model at the 5% level of significance as well as on "Only-Process-Inno" in the four-alternative logit model at the 10% level of significance.

Concerning both types of certified EMS, it can be shown that "ISO14001" now has a significantly positive effect on "Product-And-Process-Inno" in both multinomial logit models, albeit only at the 10% level of significance. At the same level of significance, it also has a positive influence on "Either-Product-Or-Process-Inno" in the three-alternative logit model and on "Only-Process-Inno" in the four-alternative logit model. Thus, the ISO 14001 certification obviously has some positive effects on environmental innovations that are overlapped in the binary probit analysis due to the discussed problems. Against it, the EMAS certification has no significant influence on any type of environmental innovations in both multinomial logit models, either. Altogether, the ISO 14001 certification seems to have some potential to stimulate environmental innovations.

In contrast, the effects of the single environmental organizational measures are again stronger since "Lifecycle" and "Disposal" have a positive influence on "Product-And-Process-Inno" in both multinomial logit models at the 5% level of significance. Furthermore, measures concerning the disposal or withdrawal of products have a positive influence on "Either-Product-Or-Process-Inno" and on "Only-Product-Inno" at the 5% level of significance. Thus, it seems that specific measures such as product design with life cycle analysis and take back systems for products may stimulate environmental product and process innovations to a larger extent than entire EMS. Measures concerning the disposal or withdrawal of products additionally have a particularly strong effect on environmental product innovations. Finally, the ISO 9001 certification (like the ISO 14001 certification) has a significantly positive effect on "Product-And-Process-Inno" in both multinomial logit models and on "Only-Process-Inno" in the four-alternative logit model, albeit at a 10% level of significance. Thus, it seems that certified general management quality standards are not less important for environmental innovations than certified EMS.

Indeed, it is possible that the effects of "ISO14001" and "EMAS" may overlap each other due to their relatively strong positive relationship (the correlation coefficient between both variables is 0.3520). Therefore, we have also considered discrete choice models replacing the two variables of certified EMS with either "ISO14001" or "EMAS" (the estimation results are not displayed for brevity). However, the parameter estimates have been very similar to the parameter estimates in Table 2 and Table 3. The EMAS certification has not had a significant effect on any type of environmental innovations in these binary probit and multinomial logit models, either. Concerning the ISO 14001 certification, the only qualitative difference is that it has had a positive effect on "Process-Inno" at the 10% level of significance and on "Product-Or-Process-Inno" at the 5% level of significance in the corresponding binary probit models. Based on the estimations according to Table 2 and Table 3, we have beyond also examined the common effect of "ISO14001" and "EMAS", i.e. utilizing the Wald and the likelihood ratio test, we have tested the null hypothesis that the corresponding parameters together are zero. The result has been that this hypothesis could not be rejected at the 10% level of significance in all binary probit and multinomial logit models (in contrast to the testing of the common effect of "Lifecycle" and "Disposal"). Note that this result has even held true if the common effect of "ISO14001" and "EMAS" has only be tested on the several alternatives in the three-alternative and four-alternative logit models.

Finally, we have also constructed two common variables of certified EMS. The first dummy variable takes the value one if there exists presently both an ISO 14001 and an EMAS certification in one or more facilities of a company. The second dummy variable takes the value one if at least one facility of a company is presently certified according to ISO 14001 or EMAS. The estimation results (not displayed for brevity) in the corresponding binary probit and multinomial logit models replacing "ISO14001" and "EMAS" with one of these two dummy variables have shown that the first common variable of certified EMS has never had a significant effect on any type of environmental innovations. Thus, a double certification for ISO14001 and EMAS seems to have no potential to stimulate environmental innovations at all due to the non-existing effect of the EMAS certification. In contrast, the second common variable of certified EMS has had a positive effect on "Process-Inno" and on "Product-Or-Process-Inno" at the 10% level of significance in the corresponding binary probit models. But most notably, this variable has had a positive effect on "Product-And-Process-Inno" at the 5% level of significance in both multinomial logit models. Thus, a certification with at least one of these standards seems to have a higher potential to stimulate both the realization of an environmental product and a process innovation than only the ISO 14001 certification. Nevertheless, note that in contrast to the strong positive effects of "Life-cycle" and/or particularly "Disposal", this effect is rather specific since it has only arisen in the multinomial logit models compared with the realization of no environmental innovation. Against it, this variable has not had a significant influence on "Either-Product-Or-Process-Inno" in the three-alternative or on "Only-Product-Inno" and "Only-Process-Inno" in the four-alternative logit model.

In the last step, we check the estimation results in the multinomial logit models according to Table 3 on robustness through a multinomial probit analysis. Table 4 reports the corresponding estimation results in the three-alternative and four-alternative probit models. Concerning the three-alternative probit model, the results are qualitatively nearly identical compared with the three-alternative logit model (note that the parameter estimates differ due to different identification restrictions). Only "Comp-Factor-Client" has a positive effect on "Product-And-Process-Inno" at the higher 10% level of significance. We have also experimented with different numbers of random draws in the GHK simulator with nearly identical estimation results. In a nutshell, this means that the restrictive assumptions of the multinomial logit model are not problematic to such an extent in this three-alternative discrete choice model (similar to the estimation results in the three-alternative logit model

Table 4: Parameter estimates in the multinomial probit models

	Basic alternative: No-Inno				
	Three-alternative probit model		Four-alternative probit model		
Explanatory variables	Product-And-Process-Inno	Either-Product-Or-Process-Inno	Product-And-Process-Inno	Only-Product-Inno	Only-Process-Inno
Constant	-2.7010** (-3.48)	-1.2678** (-2.25)	-2.8806** (-3.53)	-2.3328 (-0.60)	-1.3946** (-2.50)
ISO14001	0.5259* (1.76)	0.4423* (1.83)	0.5090* (1.71)	0.4281 (1.63)	0.4277* (1.79)
EMAS	0.1690 (0.37)	-0.0874 (-0.23)	0.1945 (0.42)	-0.1133 (-0.23)	-0.0748 (-0.20)
Lifecycle	0.7449** (2.33)	0.1067 (0.38)	0.7643** (2.32)	-0.1196 (-0.10)	0.1309 (0.46)
Disposal	0.6551** (2.91)	0.3915** (2.26)	0.6573** (2.83)	0.5242 (1.02)	0.3753** (2.00)
ISO9001	0.4530* (1.89)	0.2727 (1.55)	0.4537* (1.87)	0.1920 (0.46)	0.2969 (1.61)
Comp-Pressure	0.1413 (0.61)	-0.2284 (-1.29)	0.1798 (0.71)	-0.1217 (-0.35)	-0.2288 (-1.22)
Comp-Factor-Client	0.7943* (1.94)	0.1869 (0.73)	0.8471* (1.93)	0.3010 (0.77)	0.2140 (0.82)
Comp-Factor-Environment	0.7485** (2.87)	0.3336 (1.52)	0.7594** (2.92)	0.5366 (0.73)	0.2757 (0.90)
R&D	0.9150** (3.23)	0.4612** (2.39)	0.9117** (3.19)	0.4668** (2.03)	0.4524** (2.33)
Exports	0.1945 (0.58)	0.2586 (1.17)	0.2192 (0.64)	0.5973 (0.52)	0.2569 (1.06)
Ln-Employees-Squared	2.9322** (2.54)	2.5860** (2.65)	3.0641** (2.64)	2.8905* (1.74)	2.6714** (2.76)
Reciprocal-Age	-0.7404** (-2.76)	-0.6825** (-3.38)	-0.6827** (-2.57)	-0.8017 (-1.19)	-0.6101** (-2.92)
Reciprocal-Age-Squared	1.9372** (3.30)	1.6815** (3.58)	1.8109** (3.16)	1.9810 (1.22)	1.4958** (3.01)
One-Facility	0.0704 (0.30)	0.1653 (0.98)	0.1033 (0.44)	0.2748 (0.79)	0.1964 (1.16)

Remarks:
All estimations include eight industry dummies and one regional dummy (for Western Germany).
Z-statistics in parentheses. * (**) means that the null hypothesis that the appropriate parameter is zero can be rejected at the 10% (5%) level of significance (according to the corresponding two-tailed test). $N = 390$.

in Rennings et al., 2004) and that the conclusions from the three-alternative logit model can be held.

Regarding the four-alternative probit model, the most important conclusions from the four-alternative logit analysis can likewise be held. It should be emphasized that in no case, a significantly positive effect in one model comes along with a significantly negative effect in the other model. Particularly the results for the three variables "ISO14001", "EMAS", and "Lifecycle" of environmental organizational measures (as well as for "One-Facility") are qualitatively unaffected by the application of the different four-alternative discrete choice models. Only for one parameter estimate at all ("ISO9001" with regard to "Only-Product-Inno"), the algebraic sign changes with values near zero. However, some qualitative differences to the four-alternative logit model arise. In most cases, the effects of some variables particularly on "Only-Product-Inno" become less or even no longer significant. This holds true for "Disposal", "Comp-Factor-Environment", "Exports", and the firm size and firm age variables. Furthermore, the influences of "ISO9001" and "Comp-Pressure" on "Only-Process-Inno" as well as of "Comp-Factor-Client" on "Product-And-Process-Inno" are also less or no longer significant. Thus, the conclusions concerning the effects of customer satisfaction or environmental issues as an important competition factor on environmental innovations must be slightly weakened. In contrast, there are three cases where the positive effects become more significant, namely the influence of "Disposal" and "R&D" on "Only-Process-Inno" as well as the influence of "R&D" on "Only-Product-Inno". Thus, it seems that particularly the absorption ability concerning technological opportunities is even better suited to stimulate environmental product or process innovations as it arises from the prior analysis.

However, note that the estimation results in the four-alternative probit model should be treated with caution. We have also experimented with different numbers of random draws in the GHK simulator. The result has been that the loglikelihood function has not converged to a maximum in several cases (e.g. for 10 or 500 random draws in the GHK simulator). Furthermore, the estimates of the five variance covariance parameters in Σ_4 (the results are not displayed for brevity) have been extremely unstable. These problems seem to be a consequence of the structure of the included explanatory variables since we do not have explanatory variables that vary between the alternatives of the dependent variable (see Keane, 1992). Indeed, without such alternative specific variables, practical identification of simulated or unsimulated maximum likelihood estimations of multinomial probit models is often difficult, although the models are formally identified (see also the results in Rennings et al., 2004). Thus, it would be interesting to examine in such a context as in this paper where no alternative specific explanatory variables are available whether the flexible multinomial probit model (in spite of the problems in practical identification) or the simple multinomial logit model (in spite of the restrictive IIA property) is superior. Such an analysis based on Monte Carlo experiments is left for further research.

6 Conclusions

This paper examines the determinants of different types of environmental innovations. Such innovations receive increasing attention from policy makers and scholars since they are expected to produce a double dividend, i.e. limit environmental burden and contribute to the technological modernization of the economy. However, the incentives to produce such a double dividend are weak due to market failures. The costs for an environmental innovation have to be borne by a single firm, although the whole society benefits from such a measure due to positive spillovers. Even if an environmental innovation can be successfully marketed, it is difficult for the company to appropriate the profits of this innovation if the corresponding knowledge is easily accessible for imitators and the environmental benefits have a public good character. Based on a binary and multinomial discrete choice analysis at the firm level in the German manufacturing sector, we show that particularly R&D activities have a significantly strong positive effect on both environmental product and process innovations. Thus, these technological opportunities may also stimulate environmental innovations as it has been recognized in industrial economics concerning innovations in general. This partly holds true for other well known variables included in this literature such as market pull factors. In contrast, neither the financial situation nor the skill structure have a significant effect on any type of environmental innovations.

Concerning environmental organizational measures, the most important result is that single measures such as product design with life cycle analysis and take back systems for products have a significantly strong positive effect on environmental product and process innovations. In contrast, the effects of certified EMS are statistically less reliable. While the world-wide ISO 14001 standard has a significantly weak positive influence, the European EMAS standard has no significant effect on environmental innovations at all. A certification with at least one of these standards has a significantly positive effect on both the realization of an environmental product and a process innovation. However, this influence only holds true compared with the absence of environmental innovations. Thus, some specific environmental organizational measures obviously may still stimulate environmental innovations to a larger extent than entire EMS. In the framework of the discussion of so-called soft environmental policy instruments such as initiatives concerning the certification for EMS, this means that the contribution of such programs to environmental technological innovation is not completely clear. In the future, it seems to be promising to analyze how far single measures such as life cycle considerations are applied. Concerning some incentives for the realization of environmental organizational measures or more directly for the realization of environmental technological innovations, policy could consider the opportunity of rewards e.g. in public procurement apart from only supporting initiatives concerning the certification for EMS.

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References

[1] Anton, W.R.Q., G. Deltas and M. Khanna (2004), Incentives for Environmental Self-Regulation and Implications for Environmental Performance, *Journal of Environmental Economics and Management*, forthcoming.

[2] Arora, S. and T.N. Carson (1995), An Experiment in Voluntary Environmental Regulation: Participation in EPA's 33/50 Program, *Journal of Environmental Economics and Management* 28, 271-286.

[3] Börsch-Supan, A. and V.A. Hajivassiliou (1993), Smooth Unbiased Multivariate Probability Simulators for Maximum Likelihood Estimation of Limited Depenedent Variable Models, *Journal of Econometrics* 58, 347-368.

[4] Brunnermeier, S.B. and M.A. Cohen (2003), Determinants of Environmental Innovation in US Manufacturing Industries, *Journal of Environmental Economics and Management* 45, 278-293.

[5] Carraro, C. (2000), Environmental Technological Innovation and Diffusion: Model Analysis, in: Hemmelskamp, J., F. Leone and K. Rennings (Eds.): *Innovation-oriented Environmental Regulation: Theoretical Approaches and Empirical Analysis*, Heidelberg, New York, 269-297.

[6] Cleff, T. and K. Rennings (1999), Determinants of Environmental Product and Process Innovation, *European Environment* 9 (5), 191-201.

[7] Czarnitzki, D. (2002), *Research and Development: Financial Constraints and the Role of Public Funding for Small and Medium-Sized Firms*, Discussion Paper No. 02-74, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim.

[8] Dasgupta, S., H. Hettige and D. Wheeler (2000), What Improves Environmental Compliance? Evidence from Mexican Industry, *Journal of Environmental Economics and Management* 39, 39-66.

[9] DeCanio, S.J. and W.E. Watkins (1998), Investments in Energy Efficiency: Do the Characteristics of Firms Matter?, *The Review of Economics and Statistics* 80, 95-107.

[10] Ebling, G. and N. Janz (1999), *Export and Innovation Activities in the German Service Sector: Empirical Evidence at the Firm Level*, Discussion Paper No. 99-53, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim.

[11] Geweke, J., M. Keane and D. Runkle (1994), Alternative Computational Approaches to Inference in the Multinomial Model, *The Review of Economics and Statistics* 76, 609-632.

[12] Gottschalk, S. and N. Janz (2003), Bestimmungsfaktoren der Innovationstätigkeit, in: Janz, N. and G. Licht (Eds.), *Innovationsforschung heute*, ZEW Wirtschaftsanalysen, Bd. 63, Baden-Baden, 41-72.

[13] Greene, W.H. (2000), Econometric Analysis, Fourth Edition, New Jersey.

[14] Harabi, N. (1997), *Determinanten des technischen Fortschritts auf Branchenebene: Ein Überblick*, Discussion Paper No. 97-02, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim.

[15] Henriques, I. and P. Sardorsky (1996), The Determinants of an Environmentally Responsive Firm: An Empirical Approach, *Journal of Environmental Economics and Management* 30, 391-395.

[16] Jaffe, A.B. and K. Palmer (1997), Environmental Regulation and Innovation: A Panel Data Study, *The Review of Economics and Statistics* 79, 610-619.

[17] Jaffe, A.B., R.G. Newell and R.N. Stavins (2002), Environmental Policy and Technological Change, *Environmental and Resource Economics* 22, 41-69.

[18] Keane, M. (1992), A Note on Identification in the Multinomial Probit Model, *Journal of Business and Economic Statisics* 10 (2), 193-200.

[19] Keane, M. (1994), A Computationally Practical Simulation Estimator for Panel Data, *Econometrica* 62 (1), 95-116.

[20] Khanna, M. and W.R.Q. Anton (2002), Corporate Environmental Management: Regulatory and Market-Based Incentives, *Land Economics* 78, 539-558.

[21] Khanna, M. and L.A. Damon (1999), EPA's Voluntary 33/50 Program: Impact on Toxic Releases and Economic Performance of Firms, *Journal of Environmental Economics and Management* 37, 1-25.

[22] McFadden, D. (1973), Conditional Logit Analysis of Qualitative Choice Behavior, in: Zarembka, P. (Ed.), *Frontiers in Econometrics*, New York, 105-142.

[23] Nakamura, M., T. Takahashi and I. Vertinsky (2001), Why Japanese Firms Choose to Certify: A Study of Managerial Responses to Environmental Issues, *Journal of Environmental Economics and Management* 43, 23-52.

[24] OECD-Organisation for Economic Co-operation and Development (1997), OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data - Oslo-Manual, OECD/Eurostat, Paris.

[25] Pavitt, K. (1984), Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory, *Research Policy* 13, 343-373.

[26] Rennings, K. (2000), Redefining Innovation - Eco-Innovation Research and the Contribution from Ecological Economics, *Ecological Economics* 32, 319-332.

[27] Rennings, K. and T. Zwick (2002). The Employment Impact of Cleaner Production on the Firm Level - Empirical Evidence from a Survey in Five European Countries, *International Journal of Innovation Management* 6 (3), 319-342.

[28] Rennings, K., A. Ziegler and T. Zwick (2004), The Effect of Environmental Innovations on Employment Changes: An Econometric Analysis, *Business Strategy and the Environment*, forthcoming.

[29] Rennings, K., A. Ziegler, K. Ankele, E. Hoffmann and J. Nill (2003), *The Influence of the EU Environmental Management and Auditing Scheme on Environmental Innovations and Competitiveness in Germany: An Analysis on the Basis of Case Studies and a Large-Scale Survey*, Discussion Paper No. 03-14, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim.

[30] White, H. (1982), Maximum Likelihood Estimation of Misspecified Models, *Econometrica* 50 (1), 1-25.

[31] Ziegler, A. (2001), *Simulated z-Tests in Multinomial Probit Models*, Discussion Paper No. 01-53, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim.

[32] Ziegler, A. (2002), *Simulated Classical Tests in the Multiperiod Multinomial Probit Model*, Discussion Paper No. 02-38, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim.