Disentangling Specific Subsets of Innovations: A Micro-Econometric Analysis of their Determinants

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Abstract

Based on a unique firm-level data set from the German manufacturing sector, this paper disentangles environmental and non-environmental product and process innovations. The multivariate probit analysis shows that the various innovation types are determined by different factors. The estimation results suggest a policy mix which comprises the encouragement of R&D activities, certified management systems, and specific management activities referring to environmentally friendly products when the implementation of all innovation types is to be supported.

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1. Introduction

Corporate innovations are an important component in the process of technological change and economic growth and also lead to positive externalities. Whereas the society benefits from innovations, the costs have to be predominantly borne by a single firm. As a consequence, these externalities could result in a suboptimal extent of innovations, which makes them very interesting for policy makers and scholars. Innovation activities have therefore been micro-econometrically analyzed in industrial economics since the availability of appropriate disaggregated data. While one important strand of this literature examines the effects of innovations on corporate economic performance (e.g., Griliches, 1981, Toivanen et al., 2002, Czarnitzki and Kraft, 2004b, 2006, 2008), other studies consider the determinants of innovations (e.g., Lunn, 1986, Brouwer and Kleinknecht, 1996, Brouwer et al., 1999, Galende and de la Fuente, 2003, Czarnitzki and Kraft, 2004a, Czarnitzki, 2006) or also of changes of innovations over time (e.g., Brouwer and Kleinknecht, 1999a). These analyses have in common that they consider general innovation activities.

Against this background, the determinants of one specific subset of innovations, namely environmental innovations, have recently been focused on in environmental economics (e.g., Brunnermeier and Cohen, 2003, Rehfeld et al., 2007, Wagner, 2007, 2008, Frondel et al., 2008, Horbach, 2008). This type of innovation has also received increasing attention from (environmental) policy because it does not only produce the knowledge spillovers of all innovations, but additionally limits the environmental burden and therefore leads to a further positive externality. A further stimulus of some of these studies is the empirical testing of the famous Porter hypothesis (Porter and van der Linde, 1995), which suggests that environmental regulation may have a positive impact on innovations and even on economic performance. Based on this, the effect of pollution abatement expenditures (as environmental regulation indicator) is not only analyzed for specific (sectoral) environmental innovations (e.g., Brunnermeier and Cohen, 2003), but also for (sectoral) innovations in general (e.g., Jaffe and Palmer, 1997).

Many of these micro-econometric studies incorporate R&D measures or (environmental) patents as innovation indicators. However, these indicators seem to be problematic (e.g., Brouwer and Kleinknecht, 1999b) because R&D is obviously only an input of the innovation process, and patents need not necessarily be translated into new products or processes. Therefore, new output indicators for innovations were developed since the beginning of the 1990s, for example, within the Community Innovation Surveys (CIS) which are conducted in several European countries. Moreover, it is shown that the distinction between product and process innovations is important regarding their impact on economic performance (e.g., Cabagnols and Le Bas, 2002). While product innovations are more related to product differentiation, process innovations are rather a means of reducing costs, so that it is also likely that the determinants of these innovation types differ (e.g., Lunn, 1986). As a consequence, the determinants of general product and process innovations (e.g., Flaig and Stadler, 1994, Baldwin et al., 2002, Cabagnols and Le Bas, 2002, Martínez-Ros and Labeaga, 2002, Labeaga and Martínez-Ros, 2005), including both environmental and non-environmental innovations, respectively, as well as the specific determinants of environmental product and process innovations (e.g., Ziegler and Rennings, 2004, Wagner, 2007, 2008) have also been separately micro-econometrically analyzed. By focusing on the effect of works councils, Askildsen et al. (2006) furthermore consider both the determinants of environmental product innovations, as well as the determinants of product and process innovations in general. However, their study neither examines environmental process nor non-environmental innovations.

Knowledge about the relationship between environmental and non-environmental innovations, which have not been empirically considered so far, seems to be crucial for reliable policy conclusions, because it is likely that different types of disaggregated product and process innovations are – similar to general product and process innovations – determined by different factors. For example, it is not clear a priori whether the public support of R&D activities also fosters environmental innovations and not only general product and process innovations. Furthermore, it could be hypothesized that another direction of (environmental) regulation, namely certified environmental management systems (EMS) according to ISO 14001 (established by the International Organization for Standardization) or EMAS (Eco-Management and Audit Scheme), specifically affect environmental process innovations and not other types of innovations. Based on a unique firm-level data set from the German manufacturing sector, this paper thus further disentangles different subsets of innovations. On the basis of insights from industrial and environmental economics as well as management science, we especially examine the determinants of these various innovation types.

The remainder of the paper is organized as follows: The second section discusses our concept of innovation types and the explanatory variables of the econometric analysis. The third section explains the data and the econometric model specifications. The final section discusses the main estimation results and draws some conclusions.

2. Conceptual approach

2.1. Innovation types

Regarding our definition of innovations, we conceptually refer to the Oslo Manual of OECD and Eurostat (2005): According to this, a product innovation is the introduction of a good that is new or significantly improved with respect to its characteristics or intended uses. This includes, for example, significant improvements in technical specifications, components, and materials. In contrast, a process innovation is the implementation of a new or significantly improved production method. Two common features of product and process innovations are that they must have already been implemented (i.e. new or significantly improved products must have been introduced on the market and new or significantly improved processes must have been brought into actual use in the firm's operations) and that they only have to be new to the firm itself, not necessarily to the market.

Environmental product and process innovations as specific innovation types consist of new or significantly improved products and processes which additionally avoid or reduce environmental pollution (e.g., Ziegler and Rennings, 2004). According to this, we can distinguish "Product innovations" and "Process innovations" which, respectively, can include both environmental and non-environmental innovations, as well as between "Environmental innovations" and "Non-environmental innovations" which, respectively, can incorporate both product and process innovations. To further disentangle these innovation types, we can finally distinguish "Environmental product innovations", "Environmental process innovations", "Non-environmental product innovations", and "Non-environmental process innovations".

2.2. Explanatory variables for innovations

For our econometric analysis of the determinants of innovations, we consider – according to the famous Schumpeter hypothesis – firm size, measured by "Employees", which is the natural logarithm of the number of employees. The effect of firm size on innovation behavior is unclear a priori because positive impacts (e.g., due to scale advantages of large firms) and negative impacts (e.g., due to higher flexibility of small firms) are possible (e.g., Brouwer and Kleinknecht, 1996). In addition, the dummy "One facility" which takes the value one if the firm consisted of only one facility, is also incorporated. This variable can be considered an indicator for reduced technological opportunities to use inter-firm spillover effects, so that negative effects of it on innovations are likely (e.g., Askildsen et al., 2006). Moreover, R&D is a key indicator for technological capabilities comprising physical and knowledge capital stock of a firm, and therefore seems to be a major input into the innovation process (e.g., Baldwin et al., 2002), so that it should strongly affect innovation output. We first examine the dummy "R&D" which takes the value one if a firm carried out such R&D activities.

Furthermore, we consider market and competition factors such as the dummy "Increased competition", which takes the value one if the firm stated that competitive pressure would increase in the next three years. This direct indicator of competition intensity can be expected to positively affect innovation activities (e.g., Cabagnols and Le Bas, 2002). In contrast, the impact of "Sales ratio consumers", which is the percentage of sales to consumers (divided by 100), is not clear a priori because the importance of consumer or industrial customer relationships for innovations is ambiguous. We also include three indicators for demand pull (e.g., Horbach, 2008), namely the dummies "Prices important", "Quality important", and "Customers important" that take the value one if a firm stated, respectively, that prices, quality, and customers were an important factor in delivering competitive advantages on the most important sales market in the last three years. While prices and quality can be hypothesized to especially affect production processes and therefore process innovations, customers seem to be more relevant for product innovations. Finally, it is likely that competitive pressure from international markets, i.e. participation in international competition (e.g., Czarnitzki and Kraft, 2004a), has a positive impact on innovation behaviour. We consider two dummies, "Main market abroad" and "Exports", which take the value one, respectively, if the main market was abroad (and not national or regional, e.g., Askildsen et al., 2006) in the last three years and if the firm exported.

Moreover, it can be expected that organizational activities or management practices enable the development of strategic resources, which can have a positive impact on innovation capabilities in general (e.g., Wagner, 2007). The underlying resource-based view of the firm (e.g., Wernerfelt, 1984, Barney, 1991) emphasizes the importance of internal capabilities or resources which are valuable, rare, and difficult to imitate or substitute and therefore fundamental for attaining competitive advantages (e.g., Russo and Fouts, 1997) as well as for innovation activities (e.g., Galende and de la Fuente, 2003). One important environmental activity refers to the certification of EMS. EMS certifications have recently played a crucial role in the discussion of voluntary environmental programs as a proactive approach to environmental protection (e.g., Khanna, 2001) and have, for example, been analyzed with respect to their impacts on corporate environmental performance (e.g., Arimura et al., 2008). These programs are considered useful supplements to traditional mandatory command-and-control regulations and economic incentives (e.g., Alberini and Segerson, 2002). Another more general indicator in this context is a certified quality management system (e.g., Wagner, 2008). Accordingly, we first consider the dummies “EMS”, which takes the value one if at least one facility was certified according to ISO 14001 or EMAS, and “ISO 9001”, which takes the value one if at least one facility was certified according to ISO 9001. Due to the focus of these certified management systems on production processes, it can be hypothesized that they mostly affect process innovations, with “EMS” influencing environmental process innovations in particular. We also examine the two dummies “Life cycle” and “Disposal” for specific environmental management practices which take the value one, respectively, if the firm performed environmental life cycle assessment activities and if it carried out measures concerning waste disposal or redemption of own products (e.g., Ziegler and Rennings, 2004). While the first variable is process oriented, the second rather refers to products.

We also consider two specific environmental dummies, namely “Environmental market” and “Environment important”, which, respectively, take the value one if a firm sold products on the environmental market and if a firm stated that environmental issues were an important factor in delivering competitive advantages in the last three years, respectively. These variables naturally should especially affect environmental innovations. Finally, we include some firm-specific control variables. Firm age – as a further indicator for organizational resources (e.g., Galende and de la Fuente, 2003) – can be expected to positively affect innovation activities. But it can also be thought that younger firms are more innovative in order to increase their market share (e.g., Askildsen et al., 2006). We consider "Age", which is measured as the natural logarithm of age in years. Moreover, we incorporate the dummy "Western Germany", which takes the value one if the firm operated in the Western part ("alte Bundesländer" excluding Berlin) of Germany (e.g., Czarnitzki and Kraft, 2004a). Regarding sectoral differences (e.g., Brouwer and Kleinknecht, 1999b), the included nine industry dummies are aimed at controlling for sectoral effects regarding differences, for example, in (environmental) policy or economic and technological competition (e.g., Cabagnols and Le Bas, 2002), which are also expected to affect innovations. In this respect, it should be noted that direct indicators for regulatory pressure could not be included in our analysis since they are not available for Germany. The estimations of the parameters for the sector dummies – although always included – are not reported for reasons of brevity.

3. Econometric analysis

3.1. Data

The data for our empirical analysis were collected by means of a telephone survey at the Centre for European Economic Research (ZEW) in Mannheim, Germany, in 2003. The random sample was drawn from the population of all German manufacturing firms with 50 or more employees. The interviewees were the responsible production managers (R&D manager, environmental manager, general manager) which previous case studies showed to be the most competent respondents for the survey. 588 or 24.5% of the 2399 companies that were reached participated in the survey. Statistical tests show that the stratified groups (firm size, region, industry) in the sample do not significantly deviate from the shares in the population. Therefore, sample selection is not a strong problem. We exclude firms founded in the years 2002 or 2003, because some variables refer to the period between 2001 and 2003, and firms with incomplete data for an examined variable. As a consequence, between 372 and 386 firms are first included in the econometric analysis. Regarding the different innovation types, the firms were asked about their implementation in this period and additionally whether they planned to implement such innovations by the end of 2005, independently of any innovation activity in the past. For our econometric analysis, we first consider the future innovations and thus examine lagged explanatory variables to circumvent potential endogeneity problems.

3.2. Model specifications

While the determinants of the pairs "Product innovations" and "Process innovations" as well as "Environmental innovations" and "Non-environmental innovations" are, respectively, together analyzed in bivariate (binary) probit models (e.g., Flaig and Stadler, 1994), the determinants of "Environmental product innovations", "Environmental process innovations", "Non-environmental product innovations", and "Non-environmental process innovations" are jointly examined in multivariate (binary) probit models with four equations (see Appendix 1). Besides the estimation of the parameters of the explanatory variables, these models incorporate the estimation of correlation coefficients between the two or four dependent dummy variables in the corresponding stochastic components of the underlying latent variables. If these correlations are not considered, biased and inconsistent parameter estimates are possible due to relationships between different innovation types. While multivariate probit models in the bivariate case are straightforwardly estimated by the maximum likelihood method, we have to apply the simulated counterpart of this method which incorporates the Geweke-Hajivassiliou-Keane (GHK) simulator (Börsch-Supan and Hajivassiliou, 1993, Geweke et al., 1994, Keane, 1994) for the estimation in the four equation case (see Appendix 1). In this respect, we first use 50 random draws in the GHK simulator. Furthermore, we always consider the robust estimations of the standard deviation of the parameter estimates (White, 1982).

While Table 1 reports the estimation results in the two bivariate probit models, Table 2 reports the corresponding results in the multivariate probit model with four equations (see Appendix 2). Both tables show significantly positive correlation coefficients, particularly between environmental and non-environmental process innovations as well as between both types of non-environmental innovations (the only exception is the insignificant correlation between environmental process and non-environmental product innovations). This expected result underpins the importance of applying multivariate instead of univariate probit models. Moreover, both tables imply that, for example, “R&D” has the highest impact over all types of innovations at least at the 5% significance level. Furthermore, “EMS” – in the same way as “ISO 9001” – has a positive impact on environmental process innovations at the 5% significance level, and “ISO 9001” has an additional significantly positive effect on environmental innovations.

However, instead of discussing the estimation results in Table 1 and Table 2 in more detail here, we mention that the robustness of these results are tested in several additional estimations (these further estimation results are not reported for reasons of brevity, but are available on request). Regarding higher or lower numbers of random draws in the GHK simulator for the simulated maximum likelihood estimation of the multivariate probit model with four equations, for example, the results are qualitatively nearly identical with those in Table 2, even with only ten random draws. Moreover, we consider a model specification which substitutes “R&D” by a dummy for the existence of an R&D department (e.g., Brouwer et al., 1999) as a stronger indicator for technological capabilities. Another specification incorporates two separate dummies for the certification according to ISO 14001 or EMAS (e.g., Ziegler and Rennings, 2004) instead of the joint variable “EMS”. Furthermore, we examine the inclusion of two additional explanatory variables, namely an indicator for external financial constraints (e.g., Czarnitzki, 2006), measured by a dummy for a credit rating index (based on evaluations of "Creditreform", the largest German credit rating agency) and an indicator for skill structure, measured by the ratio of the number of salaried employees with a university or college degree to the number of all salaried employees. Finally, we also analyze the innovations between 2001 and 2003 as dependent variables instead of the planned innovations by the end of 2005. In line with Labeaga and Martínez-Ros (2005), it should be noted that the different innovation types are highly persistent over time due to the strong correlation coefficients which vary between 0.6 and 0.8 over both periods.

4. Main estimation results and conclusions

According to the corresponding estimations, the positive effect of the existence of an R&D department is weaker than the effect of “R&D” and, for example, even not significant for environmental process innovations. Furthermore, a main driver between ISO 14001 and EMAS certifications cannot be identified because neither of the variables ever has a significant effect on any innovation type. This is possibly due to multi-collinearity problems, which could also be responsible for the less significant impacts of “Life cycle”, for example, on non-environmental innovations when both EMS dummies are separately included. While credit rating has no significant effects on any innovation type, either, employee skills positively affect non-environmental product innovations at the 5% significance level. In contrast, these skills also have a weak negative impact on environmental innovations at the 10% significance level.

Regarding the robustness of the estimations for the shared explanatory variables over all model specifications, it should be noted that the significance of the effects can change. For example, the positive influence of “ISO 9001” is strengthened – also compared with the effect of “EMS” – in the specification incorporating a dummy for the existence of an R&D department. In this case, ISO 9001 certification has an additional positive effect on product and non-environmental product innovations at the 5% significance level, respectively. Furthermore, the positive effects of “EMS” on environmental and of “ISO 9001” on non-environmental innovations are strengthened if the credit rating and employee skills variables are included. Finally, the strongest differences with the corresponding results in Table 2 arise when the innovations between 2001 and 2003 are considered as dependent variables. In this case, the correlations in the underlying stochastic components between environmental product and non-environmental process innovations, as well as between environmental product and environmental process innovations, become insignificant. However, the estimation results from the latter two model specifications should be treated with more caution. When the credit rating and employee skills variables are included, the number of observations is lower due to the additional inclusion of these two explanatory variables. Moreover, when the innovations between 2001 and 2003 are considered as dependent variables, the interpretation of causal effects is ambiguous due to the time structure of the explanatory and dependent variables. Nevertheless, it should be emphasized that a significantly positive impact in one model specification never switches to a significantly negative impact in another one.

We now summarize the most robust estimation results over all specifications. Not surprisingly, the two environmental factors “Environmental market” and “Environment important” have a strong positive effect on environmental product innovations. Activities on the environmental market also strongly affect environmental innovations in general. Regarding firm size, the hypothesis of higher flexibility of small firms for innovation activities – and thus a negative impact of this variable – cannot be confirmed. In contrast, larger firms are more innovative, possibly due to scale advantages, although only in the case of environmental product innovations. While a high ratio of sales with industrial customers is rather more relevant for innovations and the corresponding parameters are also different from zero at the 5% significance level for process, environmental product, and non-environmental process innovations in Table 1 and Table 2, these effects are not robust in the different model specifications.

The main market and competition variable refers to quality as an important factor in delivering competitive advantages. As expected, this variable has a positive effect on process, and specifically on non-environmental process innovations. Furthermore, only non-environmental innovations are affected by competition intensity (i.e. "Increased competition"). Competitive pressure from international markets through a main market abroad has a specific positive impact on environmental product innovations. In contrast, an effect of exports and the other market and competition factors cannot be robustly confirmed. Pressures from international markets (in a similar way as firm age and regional differences between Western and Eastern Germany) are therefore obviously rather marginal for the various innovation types. These estimation results suggest that small, domestically or regionally active firms, that do not sell products on the environmental market, are a possible focus group for (environmental) policy when new or significantly improved environmentally friendly products are to be increased.

In this respect, the support of waste disposal measures, which have a robust positive effect on environmental product innovations, is also interesting. While this result is not very surprising, the impact of environmental life cycle assessment activities could not be expected a priori. These activities have a positive influence on process innovations, but to a larger extent on non-environmental process innovations. This could contradict the common perception that such assessments are mainly relevant to further corporate environmental performance. In contrast, EMS certifications in general (and not one specific certification) positively affect environmental process innovations, as expected. However, certified quality management systems are surprisingly more important in this respect. The positive impact of ISO 9001 certification on environmental process innovations is not only stronger than the corresponding impact of "EMS", but "ISO 9001" also has a positive effect on environmental innovations in general. Therefore, it can be concluded that an important direction for regulations to foster environmental innovations (and especially environmental process innovations) is rather the encouragement of any certified management systems, instead of the support of one specific EMS certification (e.g., according to ISO 14001 or EMAS). Furthermore, the public support of specific management practices such as environmental life cycle assessments or waste disposal measures can also be fruitful for specific innovation types.

Not surprisingly, however, R&D measures have the strongest effect over all innovation types. In this respect, the public encouragement of R&D activities in general is more important than the support of an independent organizational entity for R&D in the firm. While "R&D" has a high positive impact on any innovation type, it should be noted that the strongest impacts arise for product and non-environmental innovations. In other words, regulations which are directed towards the support of R&D activities can foster environmental and particularly environmental process innovations to a somewhat smaller extent. As a consequence, our estimation results overall suggest a policy mix which comprises the encouragement of R&D activities, certified management systems, and specific management activities referring to environmentally friendly products when the implementation of all innovation types is to be supported.

While this paper disentangles for the first time environmental and non-environmental product and process innovations, these four innovation types can still be considered somewhat aggregated because they consist of different kinds of innovations. For example, our definition of innovations comprises new or significantly improved products and processes that could indeed be new for the market, but essentially only have to be new for the firm itself. An analysis of the determinants of even more disaggregated (environmental and/or non-environmental) product and process innovation would therefore be interesting if corresponding data become available in the future. Another direction for further research is the consideration of dynamic effects to analyze whether or especially which (specific) innovation (types) breeds which (specific) innovation (types) (e.g., Flaig and Stadler, 1994). However, the necessary condition for such empirical analyses is the use of corresponding panel data which are not yet available. Such panel data would also be the basis for studies of specific economic effects of different innovation types.

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References

Alberini, A. and K. Segerson (2002), Assessing Voluntary Programs to Improve Environmental Quality, *Environmental and Resource Economics* 22, 157-184.

Arimura, T.H., A. Hibiki, and H. Katayama (2008), Is a Voluntary Approach an Effective Environmental Policy Instrument? A Case for Environmental Management Systems, *Journal of Environmental Economics and Management* 55, 281-295.

Askildsen, J.E., U. Jirjahn, and S.C. Smith (2006), Works Councils and Environmental Investment: Theory and Evidence from German Panel Data, *Journal of Economic Behavior and Organization* 60, 346-372.

Baldwin, J., P. Hanel, and D. Sabourin (2002), Determinants of Innovative Activity in Canadian Manufacturing Firms, in: Kleinknecht, A. and P. Mohnen (eds.), *Innovation and Firm Performance: Econometric Explorations of Survey Data*, Palgrave, 86-111.

Barney, J.B. (1991), Firm Resources and Sustained Competitive Advantage, *Journal of Management* 17, 99-120.

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

Brouwer, E. and A. Kleinknecht (1996), Firm Size, Small Business Presence and Sales of Innovative Products: A Micro-Econometric Analysis, *Small Business Economics* 8, 189-201.

Brouwer, E. and A. Kleinknecht (1999a), Keynes-Plus? Effective Demand and Changes in Firm-Level R&D: An Empirical Note, *Cambridge Journal of Economics* 23, 385-391.

Brouwer, E. and A. Kleinknecht (1999b), Innovative Output, and a Firm's Propensity to Patent. An Exploration of CIS Micro Data, *Research Policy* 28, 615-624.

Brouwer, E., H. Budil-Nadvornikova, and A. Kleinknecht (1999), Are Urban Agglomerations a Better Breeding Place for Product Innovation? An Analysis of New Product Announcements, *Regional Studies* 33, 541-549.

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.

Cabagnols, A. and C. Le Bas (2002), Differences in the Determinants of Product and Process Innovations: The French Case, in: Kleinknecht, A. and P. Mohnen (eds.), *Innovation and Firm Performance: Econometric Explorations of Survey Data*, Palgrave, 112-149.

Czarnitzki, D. (2006), Research and Development in Small and Medium-Sized Enterprises: The Role of Financial Constraints and Public Funding, *Scottish Journal of Political Economy* 53, 335-357.

Czarnitzki, D. and K. Kraft (2004a), An Empirical Test of the Asymmetric Models on Innovative Activity: Who Invests More into R&D, the Incumbent or the Challenger?, *Journal of Economic Behavior and Organization* 54, 153-173.

Czarnitzki, D. and K. Kraft (2004b), Innovation Indicators and Corporate Ratings: Evidence from German Firms, *Economics Letters* 82, 377-384.

Czarnitzki, D. and K. Kraft (2006), R&D and Firm Performance in a Transition Economy, *Kyklos* 59, 481-496.

Czarnitzki, D. and K. Kraft (2008), On the Profitability of Innovative Assets, *Applied Economics*, forthcoming.

Flaig, G. and M. Stadler (1994), Success Breeds Success. The Dynamics of the Innovation Process, *Empirical Economics* 19, 55-68.

Frondel, M., J. Horbach, and K. Rennings (2008), What Triggers Environmental Management and Innovation? Empirical Evidence for Germany, *Ecological Economics* 66, 153-160.

Galende, J., J.M. de la Fuente (2003), Internal Factors Determining a Firm's Innovative Behaviour, *Research Policy* 32, 715-736.

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.

Greene, W.H. (2003), *Econometric Analysis*, Prentice Hall.

Griliches, Z. (1981), Market Value, R&D, and Patents, *Economics Letters* 7, 183-187.

Horbach, J. (2008), Determinants of Environmental Innovation – New Evidence from German Panel Data Sources, *Research Policy* 37, 163-173.

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

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

Khanna, M. (2001), Non-Mandatory Approaches to Environmental Protection, *Journal of Economic Surveys* 15, 291-324.

Labeaga, J.M. and E. Martínez-Ros (2005), *Persistence and Ability in the Innovation Decisions*, Working Paper 2005-16, FEDEA Madrid.

Lunn, J. (1986), An Empirical Analysis of Process and Product Patenting: A Simultaneous Equation Framework, *The Journal of Industrial Economics* 34, 319-330.

Martínez-Ros, E. and J.M. Labeaga (2002), Modelling Innovation Activities Using Discrete Choice Panel Data Models, in: Kleinknecht, A. and P. Mohnen (eds.), *Innovation and Firm Performance: Econometric Explorations of Survey Data*, Palgrave, 150-171.

OECD and Eurostat (2005), *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, Paris.

Porter, M.E. and C. van der Linde (1995), Toward a New Conception of the Environment-Competitiveness Relationship, *Journal of Economic Perspectives* 9, 97-118.

Rehfeld, K.-M., K. Rennings, and A. Ziegler (2007), Integrated Product Policy and Environmental Product Innovations - An Empirical Analysis, *Ecological Economics* 61, 91-100.

Russo, M.V. and P.A. Fouts (1997), A Resource-Based Perspective on Corporate Environmental Performance and Profitability, *Academy of Management Journal* 40, 534-559.

Toivanen, O., P. Stoneman, and D. Bosworth (2002), Innovation and the Market Value of UK Firms, 1989-1995, *Oxford Bulletin of Economics and Statistics* 64, 39-61.

Wagner, M. (2007), On the Relationship between Environmental Management, Environmental Innovation and Patenting: Evidence from German Manufacturing Firms, *Research Policy* 36, 1587-1602.

Wagner, M. (2008), Empirical Influence of Environmental Management on Innovation: Evidence from Europe, *Ecological Economics* 66, 392-402.

Wernerfelt, B. (1984), A Resource-based View of the Firm, *Strategic Management Journal* 5, 171-180.

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

Ziegler, A. (2007), Simulated Classical Tests in Multinomial Probit Models, *Statistical Papers* 48, 655-681.

Ziegler, A. and K. Rennings (2004), *Determinants of Environmental Innovations in Germany: Do Organizational Measures Matter? A Discrete Choice Analysis at the Firm Level*, Discussion Paper 04-30, ZEW Mannheim.

Appendix 1: Multivariate (binary) probit models

We assume that a firm i (i = 1,…,N) will implement a specific type j (j = 1,…,J) of innovation if the expected profit from realization is greater than the expected profit from not realizing it. The underlying latent unobservable variables are as follows:

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

The U_{ij} can be interpreted as an attraction measure for the profit with regard to a specific type of innovation. We assume that a firm i implements an innovation type j if $U_{ij} > 0$. Based on this, we define the observable indicator variables:

$$Y_{ij} = \begin{cases} 1 & \text{if } U_{ij} > 0 \\ 0 & \text{otherwise} \end{cases}$$

The j = 1,…,J vectors x_{ij} of the respective K_j known explanatory variables are $x_{ij} = (x_{i1},\ldots, x_{iKj})'$ and the corresponding unknown parameter vectors are $\beta_j = (\beta_1,\ldots,\beta_{Kj})'$. $P(Y_{ij} = 1)$ denotes the probability for the implementation of innovation type j. Since we consider probit models, the stochastic components ε_{ij} are standard normally distributed.

The specific assumption that the ε_{ij} are mutually independent over all j = 1,…,J innovation types leads to simple univariate (binary) probit models. Flexible multivariate (binary) probit models are based on the assumption that the ε_{ij} are jointly normally distributed with:

$$\varepsilon_i = (\varepsilon_{i1},\ldots,\varepsilon_{iJ}) \sim \mathrm{N}_J(0;\Sigma_J)$$

Instead of the one-dimensional probabilities $P(Y_{ij} = 1)$ and $P(Y_{ij} = 0)$, these models comprise for each firm i the following J-dimensional probabilities in the maximum likelihood estimation:

$$P(Y_{i1} = y_{i1},\ldots,Y_{iJ} = y_{iJ}) = \Phi_J(x_{i1},\ldots,x_{iJ};\beta_1,\ldots,\beta_J;\rho_{12},\ldots,\rho_{1J},\rho_{23},\ldots,\rho_{2J},\ldots,\rho_{J-1,J})$$

These probabilities depend on the realized values $y_{i1},\ldots,y_{iJ}$ which equal to one or zero (e.g., Greene, 2003). The log-likelihood function therefore has the following appearance:

$$\ln L = \sum_{i=1}^{N} \ln \Phi_J(x_{i1},\ldots,x_{iJ};\beta_1,\ldots,\beta_J;\rho_{12},\ldots,\rho_{1J},\rho_{23},\ldots,\rho_{2J},\ldots,\rho_{J-1,J})$$

According to this, the probabilities in multivariate probit models comprise $J(J-1)/2$ correlation coefficients in Σ_J which can be estimated besides the parameter vectors of the explanatory variables (the corresponding variance parameters in Σ_J are restricted due to model identification). In the case of the bivariate probit model with $J = 2$ the maximum likelihood estimation (which only comprises one correlation coefficient in the stochastic components) is straightforward. In contrast, the estimation of multivariate probit models with sizeable J is more complex due to the arising multiple integrals in the probabilities $P(Y_{i1} = y_{i1},\dots,Y_{iJ} = y_{iJ})$ and thus in the distribution functions $\Phi_J(\cdot)$ of the J-dimensional normal distribution. The computation of these J-dimensional integrals (in our multivariate probit model with $J = 4$ types of innovations) is not feasible with deterministic numerical integration methods. But the probabilities can be quickly and accurately approximated with (unbiased) stochastic simulation methods, i.e. with repeated transformed draws of pseudo-random numbers. By incorporating such a simulator, one obtains the simulated counterpart of $P(Y_{i1} = y_{i1},\dots,Y_{iJ} = y_{iJ})$. In comparative Monte Carlo experiments, it has been shown that the Geweke-Hajivassiliou-Keane (GHK) simulator (Börsch-Supan and Hajivassiliou, 1993, Keane, 1994, Geweke et al., 1994) outperforms other simulation methods with regard to the approximation of the true probability. The incorporation of these simulated probabilities in the maximum likelihood estimation leads to the simulated maximum likelihood estimation of multivariate probit models. Based on these estimates of the unknown parameters, simulated counterparts of classical test statistics can finally additionally be applied (e.g., Ziegler, 2007), for example, to analyze the significance of the effect of an explanatory variable.

Appendix 2: Tables

Table 1: Maximum likelihood estimates in bivariate probit models, number of observations = 382 in model 1, number of observations = 386 in model 2

	Dependent variables (model 1)		Dependent variables (model 2)	
Explanatory variables	Product innovations	Process innovations	Environmental innovations	Non-environmental innovations
Employees	0.12	0.17*	0.25***	0.02
One facility	-0.22	-0.26	0.14	0.11
R&D	1.27***	0.62***	0.46**	0.74***
Increased competition	0.47**	-0.01	-0.32*	0.39**
Sales ratio consumers	-0.21	-0.41**	-0.26	-0.19
Prices important	-0.29	-0.05	0.04	-0.62**
Quality important	-0.13	0.56**	0.14	0.39*
Customers important	-0.00	-0.28	0.31	-0.57*
Main market abroad	-0.07	-0.11	0.22	-0.00
Exports	0.13	0.14	0.26	0.41*
EMS	0.02	0.27	0.27	0.05
ISO 9001	0.25	0.19	0.35**	0.25
Life cycle	-0.03	0.82**	0.19	0.54**
Disposal	0.30*	0.14	0.30*	0.13
Environmental market	0.38	-0.41*	0.66***	0.01
Environment important	0.33	-0.15	0.30	-0.20
Age	-0.08	0.04	0.04	-0.00
Western Germany	-0.52*	-0.00	-0.13	-0.29
Constant	-0.31	-1.02	-2.18***	0.48
Wald test statistics	171.56***		146.61***	
Correlation coefficients stochastic components	0.38***		0.39***	

*Note: *** (**, *) means that the appropriate parameter is different from zero or – regarding the Wald test – that all explanatory variables together have an effect at the 1% (5%, 10%) significance level, respectively*

Table 2: Simulated maximum likelihood estimates in the multivariate probit model, number of observations = 372

	Dependent variables			
Explanatory variables	Environmental product innovations	Environmental process innovations	Non-environmental product innovations	Non-environmental process innovations
Employees	0.20**	0.14*	0.05	-0.01
One facility	0.04	0.05	-0.05	-0.15
R&D	0.44**	0.41**	1.22***	0.51***
Increased competition	0.24	-0.21	0.40**	0.19
Sales ratio consumers	-0.41**	-0.27	-0.04	-0.40**
Prices important	0.13	-0.08	-0.32	-0.30
Quality important	-0.00	0.14	-0.12	0.56***
Customers important	0.53*	0.36	-0.08	-0.41*
Main market abroad	0.30*	-0.03	-0.13	-0.16
Exports	0.28	0.06	0.22	0.38*
EMS	0.14	0.36**	-0.11	0.17
ISO 9001	0.05	0.43**	0.26	0.05
Life cycle	0.35*	0.45**	0.03	0.87***
Disposal	0.46***	0.12	0.16	0.14
Environmental market	0.95***	0.12	-0.06	-0.00
Environment important	0.63***	0.01	-0.18	-0.14
Age	-0.03	-0.01	-0.02	0.08
Western Germany	-0.25	-0.13	-0.43	-0.13
Constant	-2.96***	-1.34**	-0.37	-0.36
Simulated Wald test statistic	316.17***			
Simulated correlation coefficients stochastic components		Environmental process innovations	Non-environmental product innovations	Non-environmental process innovations
	Environmental product innovations	0.34***	0.34***	0.24**
	Environmental process innovations		0.05	0.54***
	Non-environmental product innovations			0.60***

*Note: *** (**, *) means that the appropriate parameter is different from zero or – regarding the simulated Wald test – that all explanatory variables together have an effect at the 1% (5%, 10%) significance level, respectively*