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Green Management and Green Technology – Exploring the Causal Relationship

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Non-technical Summary

Voluntary green management measures play a significant role in the discussion of non-mandatory approaches as supplements to conventional environmental policy to foster corporate environmental performance. Non-mandatory measures are thought to be more cost-efficient than mandatory command and control regulations because they leave firms the flexibility to choose the cheapest pollution abatement strategy and reduce governments' enforcement costs. An understanding of the causal relationship between green management and corporate environmental performance such as green technology activities is therefore highly important.

Some former econometric studies which regress corporate environmental performance on green management find that green management measures have a significantly positive effect. However, other studies fail to show significant impacts. We attribute this lack of clear-cut results in different studies to endogeneity problems. We argue that the corresponding parameter estimates could be biased and inconsistent due to structural reverse causality and/or unobserved firm heterogeneity.

In this paper, we try to shed more light on these potential endogeneity problems. Based on evolutionary theory and the resource-based view of the firm, we discuss in the first step that green technology could also influence green management and that unobserved firm characteristics could simultaneously influence green management and green technology. Contrary to existing studies, we empirically explore in the second step the structural reverse causality hypothesis with a unique cross-sectional firm-level data set from the German manufacturing sector. Our econometric analyses with uni- and multivariate probit models imply a significantly positive effect of environmental process innovations on certified environmental management systems and a significantly positive impact of

environmental product innovations on life cycle assessment activities. We interpret these empirical results as a further indicator that the causal relationship between green management and green technology is not clear.

We conclude that firm-level panel data, which are not available for technological environmental innovations yet, are a necessary condition to solve the endogeneity problems in econometric studies which regress green technology on green management. Unlike cross-sectional data, panel data can control for unobserved firm characteristics and can provide valid instruments for green management measures if their effect on green technology activities is analyzed. Such panel data studies could therefore be an appropriate basis for robust conclusions with regard to voluntary green management measures as a non-mandatory approach in environmental policy.

Green Management and Green Technology - Exploring the Causal Relationship

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Abstract

In this paper, we analyze potential endogeneity problems in former econometric studies which regress corporate environmental performance such as green technology activities on green management. Based on evolutionary theory and the resource-based view of the firm, we discuss in the first step that green technology could also influence green management and that unobserved firm characteristics could simultaneously influence green management and green technology. Contrary to existing studies, we empirically explore in the second step the structural reverse causality hypothesis with a unique cross-sectional firm-level data set from the German manufacturing sector. Our econometric analyses with uni- and multivariate probit models imply a significantly positive effect of environmental process innovations on certified environmental management systems and a significantly positive impact of environmental product innovations on life cycle assessment activities. We interpret these empirical results as a further indicator that the causal relationship between green management and green technology is not clear. We conclude that panel data, which are not available for technological environmental innovations yet, are a necessary condition to solve these endogeneity problems. Such panel data studies could therefore be an appropriate basis for robust conclusions with regard to voluntary green management measures as a non-mandatory approach in environmental policy.

Keywords: Non-mandatory environmental policy, green management, green technology, uni- and multivariate probit models, endogeneity, structural reverse causality, unobserved firm heterogeneity.

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Green Management and Green Technology - Exploring the Causal Relationship

1 Introduction

An understanding of the causal relationship between green management and corporate environmental performance such as green technology activities is highly important for environmental policy. Voluntary green management measures play a central role in the discussion of non-mandatory approaches to foster corporate environmental performance (Khanna, 2001). For example, voluntary environmental programs such as 33/50, which was initiated by the U.S. Environmental Protection Agency (EPA) (and aimed at reducing the releases and transfers of 17 priority chemicals by 33% between 1988 and 1992 and by 50% until 1995), are considered useful supplements to traditional mandatory command and control regulations (Arora and Cason, 1996; Khanna and Damon, 1999). Non-mandatory measures are thought to be more cost-efficient because they leave firms the flexibility to choose the cheapest pollution abatement strategy and reduce governments' enforcement costs (Alberini and Segerson, 2002). The ongoing attraction of voluntary measures in environmental policy is also reflected in the European Council's renewed "Lisbon strategy" where the reduction of red tape in the European Union (EU) is one of the primary goals (see EU Council, 2005) or in the promotion of Integrated Product Policy (IPP) by the European Commission (see EC, 2001).

Green management measures such as certified environmental management systems (EMS) or tools like life cycle assessment activities are considered to improve corporate environmental performance directly by mandating companies to introduce environmental goals and management structures as well as programs to achieve them

(Coglianese and Nash, 2001; Johnstone, 2001) and indirectly by inducing organizational learning and providing critical environmental information (Melnyk *et al.*, 2003). Some econometric studies analyzing this hypothesis actually find a positive impact. For example, Potoski and Prakash (2005) show that facilities which are certified according to the EMS standard ISO 14001, developed by the non-governmental “International Organization for Standardization” (ISO), reduce more pollution emissions than non-certified ones. Furthermore, Ziegler and Rennings (2004) and Rehfeld *et al.* (2006) find a positive effect of green management measures on green technology, i.e., future environmental product or process innovations. In contrast, Dahlström *et al.* (2003) fail to show that the ISO 14001 certification improves the compliance with environmental regulations. Furthermore, Lenox and Nash (2003) point to adverse selection problems of voluntary environmental programs (looking at the U.S. chemicals industry’s Responsible Care program) since in their study dirtier firms were more attracted to them.

We attribute this lack of clear-cut results in studies that regress corporate environmental performance on green management to endogeneity problems. We argue that the corresponding parameter estimates could be biased and inconsistent due to structural reverse causality and/or unobserved firm heterogeneity (as a specific type of omitted variables). Structural reverse causality occurs if the direction of causality between green management and environmental performance is not clear. For example, the certification of EMS according to ISO 14001 or the EU EMAS (Environmental Management and Auditing Scheme) standard could facilitate the realization of technological environmental innovations. However, these certifications could also be more attractive for already environmentally innovative firms. Unobserved firm heterogeneity arises if unobserved firm characteristics simultaneously influence green management and environmental performance.

The goal of our paper is to shed more light on these potential problems. In the first step, we theoretically analyze both types of endogeneity. Based on evolutionary theory and the resource-based view of the firm, we argue that environmental performance such as technological environmental innovations could actually influence green management. Firms which already have realized such innovations in the past are more likely to possess environmental capabilities in having overcome management barriers such as the lack of finance or know-how at least once before. Furthermore, we argue that unobserved intangible corporate environmental capabilities could simultaneously influence green management and green technology.

Contrary to existing studies, we empirically explore in the second step the structural reverse hypothesis that corporate environmental performance influences green management measures. To test this hypothesis, we apply a unique cross-sectional firm-level data set from the German manufacturing sector which is already used in the studies of Ziegler and Rennings (2004) and Rehfeld *et al.* (2006). These data comprise environmental product and process innovations which we use as measure for environmental performance. Our econometric analyses with uni- and multivariate probit models imply a significantly positive effect of environmental process innovations on certified EMS and a significantly positive impact of environmental product innovations on life cycle assessment activities. According to this, a positive relationship seems to exist. However, we consider the significant effects in our study as well as in the other studies analyzing the impact of green management on environmental performance as influenced by endogeneity problems due to structural reverse causality. We therefore interpret our empirical results as evidence for the ambiguity of the causal relationship between green management and green technology.

In the same way as Börsch-Supan and Köke (2002) (who analyze the relationship between corporate governance and firm performance), we conclude that panel data, which are not available for technological environmental innovations yet, are a necessary condition to solve these endogeneity problems. Unlike cross-sectional data, panel data can control for unobserved firm characteristics and can provide valid instruments for green management measures if their effect on green technology is analyzed. Such panel data studies could therefore be an appropriate basis for robust conclusions with regard to voluntary green management measures as a non-mandatory approach in environmental policy.

This paper is structured as follows: In the second section, we review the empirical literature on green management and corporate environmental performance. The third section gives a short overview of green management and technological environmental innovations in Germany. In the fourth section, we discuss endogeneity problems in econometric studies due to structural reverse causality and unobserved firm heterogeneity on the basis of evolutionary theory and the resource-based view of the firm. The fifth section explores the structural reverse causality hypothesis by an econometric analysis of the effect of technological environmental innovations on green management measures. The final section presents our conclusions.

2 Literature Review

The empirical literature on green management and corporate environmental performance can be categorized into studies concerning the determinants of green management, studies examining the influence of green management on environmental performance in general, and studies considering the effect of green management on technological environmental innovations (which in turn can be interpreted as specific kinds of corporate environmental performance).

Several studies in the first strand of literature focus on the determinants of firms' participation in public voluntary programs such as EPA's 33/50 (Arora and Cason, 1995, 1996) or Green Lights (DeCanio and Watkins, 1998). Other studies consider the determinants of certified EMS such as ISO 14001 or EMAS (Biondi *et al.*, 2000; Halkos and Evangelinos, 2002; Nakamura *et al.*, 2001). However, it should be noted that green management is less interesting for environmental policy than green technology activities such as technological environmental innovations because green management measures alone do not guarantee an improvement in environmental performance, for example, with regard to pollution abatement. Therefore, a preoccupation of regulators when substituting environmental mandatory command and control regulations by such non-mandatory measures is that they could be used as a fig leaf as there usually are no control mechanisms (Gunningham and Sinclair, 1998).

Concerning the second strand of literature which analyzes the influence of green management measures on corporate environmental performance, the effect is not clear. Some studies actually show positive impacts. For example, Dasgupta *et al*. (2000) find positive effects of green management measures on self-assessed compliance with environmental regulations, Anton *et al.* (2004) find that the adoption of a more comprehensive EMS reduces toxic emissions, and Potoski and Prakash (2005) find that ISO 14001 certified facilities reduce more pollution emissions than non-certified ones. Interestingly, these econometric studies point to possible endogeneity problems with regard to their measures of green management and therefore apply instrumental variables approaches. However, their instruments based on cross-sectional data are not fully convincing. In contrast to these studies, King and Lenox (2000), for example, cannot show that participation in the Responsible Care Program (initiated by the U.S. Chemical Manufacturers Association) improves the environmental performance more than non-participation. Furthermore, Dahlström *et al.* (2003) do not find that the ISO 14001 certification improves the compliance with environmental regulations and Lenox and Nash (2003) even show that dirtier firms are more attracted to public voluntary environmental programs which points to adverse selection problems of such programs.

Regarding the third strand of literature, it should be noted that the usual measures for corporate environmental performance such as toxic emissions or the compliance with environmental regulations are mostly one-dimensional indicators. In contrast, technological environmental innovations are more complex measures. They receive increasing attention from policy makers and academics since they are expected to produce a double dividend, i.e., limit the environmental burden and contribute to the technological modernization of the economy (Jaffe *et al.*, 2002).

In a study considering only EMAS certified firms, Rennings *et al.* (2006) show a positive influence of the maturity of EMS on environmental process innovations. Other studies such as Frondel *et al.* (2004; 2006) and Johnstone *et al.* (2005) which do not apply such restricted data find a positive effect of some green management measures on technological environmental innovations. Applying the same cross-sectional firm-level data set from the German manufacturing sector as in this paper, Ziegler and Rennings (2004) and Rehfeld *et al.* (2006) find that green management measures such as certified EMS, life-cycle assessment activities, or waste disposal measures have a positive effect on future environmental product or process innovations. It should be noted that the latter studies try to avoid possible biased and inconsistent parameter estimates due to endogeneity problems by using lagged explanatory variables. Furthermore, Frondel *et al.* (2004) also discuss these endogeneity problems even if they do not offer a satisfying solution to address the difficulties with their cross-sectional data.

3 Green Management Measures and Technological Environmental Innovations in Germany

Our definition of technological environmental innovations (in the same manner as Johnstone *et al*., 2005; Frondel *et al.*, 2004; 2006) is based on the conventional understanding of technological innovations in general as defined in the Oslo-Manual of the OECD and Eurostat (1997) which distinguishes between product and process innovations. This definition considers three aspects of a technological innovation: It has to be based on new technology knowledge, it must have been already implemented (i.e., new products must have been introduced on the market or new processes must have been introduced in the firm), and it only has to be new for the firm itself, not necessarily for the market. Technological environmental innovations, i.e., environmental product and process innovations, as specific kinds of technological innovations consist of new products and processes to avoid or reduce the environmental burden (Ziegler and Rennings, 2004). Due to this definition, we consider the output of the environmental innovation process and do not use environmental patents as a proxy for technological environmental innovations since these take place at the beginning of the process and do not necessarily lead to environmental product and process innovations.

In contrast, new green management measures can be considered as organizational environmental innovations. According to the Oslo-Manual of the OECD and Eurostat (1997), organizational innovations in general refer to the implementation of new management techniques such as Total Quality Management (TQM), the introduction of significantly changed organizational structures, and the implementation of new or substantially changed corporate strategic orientations. Recent certifications of EMS such as ISO 14001 and EMAS or the introduction of environmental labeling of products, life-cycle assessment activities, or waste disposal measures fulfill the definition of new management techniques such that they are organizational innovations. Due to the environmental focus, they can furthermore be considered as organizational environmental innovations.

3.1 Green Management Measures

The most widespread certified EMS is ISO 14001. By the end of December 2004, at least 90569 ISO14001 certifications were issued in 127 countries. This represents a growth of about 37% since 2003. Germany ranks seventh with 4320 certifications, behind Japan (19584), China (8862), Spain (6473), United Kingdom (6253), Italy (4785), and USA (4759) (ISO, 2005). In contrast, in Europe only a total of 3148 organizations with 4275 facilities were EMAS certified at the end of 2005. Germany ranks first with 1514 organizations and 1925 facilities. Regarding certifications per million habitants, Germany finds itself behind Austria and Denmark (EMAS Helpdesk, 2005). In Germany, EMAS certified facilities benefit from regulatory exemptions based on the EMAS privilege regulation. Certified facilities have reduced approval process and audits in the field of emissions standards and waste treatment. However, these positive incentives do not seem to outweigh the larger effort (additional reporting) and smaller international prevalence vis-à-vis its counterpart ISO 14001. A large amount of organizations refrain from EMAS recertification, resulting in a decreasing certification rate in certain industries (Behrens *et al.*, 2003).

While a certified EMS aims at internal organization and processes of firms, environmental labeling of products, life cycle assessment activities, and waste disposal measures are mainly product related. All three measures are based on the notion that a corporation (i.e., producer) should aim at improving the environmental performance of a product through its entire life. These green management measures have in common with EMS that they do not improve the environmental performance directly. Instead, it is assumed that these measures act as incentives to improve the products and therefore reduce their environmental burden. For example, changes in a product could be necessary before the product qualifies for an environmental label. Via life cycle assessment activities, the entire environmental impact of a product (or process) is ascertained which could lead the firm to a reduction of this impact. If firms consider taking back their products to dispose them, they could improve the product's recyclability.

Germany can be considered a leader in the promotion of product related green management measures. Already in 1978 the Federal Ministry for the Environment introduced the environmental label "Blauer Engel" to foster the marketing of environmentally friendly products. This label has to the day grown to include approximately 3100 products (Umweltbundesamt, 2003). In spite of this non-mandatory approach in environmental policy and an increase of the use of market-based instruments, product stewardship is still dominated by mandatory command and control regulations. For example, waste disposal measures and take-back systems in Germany are regulated by the German Recycling and Waste Management Act, the Battery Ordinance, the Ordinance on End-of-Life Vehicles, and the Electrical and Electronic Appliance Act. Producers also finance the recycling and disposal of packaging waste which is organized by the “Grüne Punkt” (Der Grüne Punkt, 2005).

3.2 Technological Environmental Innovations

It should be noted that there are no official statistics on corporate technological environmental innovations. To our knowledge, only two firm-level data sets based on surveys on environmental product and process innovations are available. The first written survey was performed 2003 in seven OECD countries including Germany (Frondel *et al.*, 2004; 2006; Johnstone *et al.*, 2005). However, this data set does not include independent information on environmental product innovations on the one hand, and environmental process innovations on the other hand, since the firms were only asked which of these technological environmental innovations they used predominantly. In contrast, the firm-level data set applied in Ziegler and Rennings (2004), Rehfeld *et al.* (2006), and in this paper comprises independent data on environmental product and process innovations of German manufacturing firms (NACE-Codes 15-37) with 50 or more employees (for details see section 5). According to this, more than one third (37.2%) of the surveyed corporations have realized environmental product innovations between 2001 and 2003. In contrast, more than two third (69.9%) of these firms have realized environmental process innovations in this period. This may be due to the fact that environmental policy in the past mainly focused on process related environmental burdens and neglected product related aspects to some extent.

4 Theoretical Attempts to Explain Possible Endogeneity Problems

The goal of this paper is to examine the causal relationship between green management measures and green technology. As discussed in the introduction, we argue that existing econometric studies, which regress corporate environmental performance on green management, could be influenced by endogeneity problems which lead to biased and inconsistent parameter estimates. In this section, we discuss theoretical explanations for two potential types of endogeneity, namely structural reverse causality and unobserved firm heterogeneity (as a specific type of omitted variables). We consider both types of endogeneity to be closely related.

4.1 Structural Reverse Causality

Evolutionary theory suggests that firm-internal characteristics such as strategy, structure, and core capabilities are important in influencing technological innovations (Elster, 1983). The firm is seen as a "[...] hierarchy of practiced organizational routines, which define lower order organizational skills, and how these are coordinated [...]" (Nelson, 1991: 68). Routines persist, even when they cease to be useful, due to the irrational resistance to change and the high costs of changing them (Nelson and Winter, 2002).

Green management measures such as certified EMS, environmental labeling of products, life-cycle assessment activities, or waste disposal measures require investments of financial resources and personnel. Firms with environmental capabilities will undertake them more easily. Firms which already have realized environmental product or process innovations in the past are more likely to possess such capabilities in having overcome management barriers such as lack of finance or know-how at least once before. It is likely that an internal learning process has already taken place. As Lam (2005: 115) puts it, "The ability of an organization to innovate is a precondition for the successful utilization of inventive resources and new technologies. Conversely, the introduction of new technology often presents complex opportunities and challenges for organizations, leading to changes in managerial practices and the emergence of new organizational forms". As a consequence, we hypothesize that technological environmental innovations (at least indirectly) could influence green management measures such as the certification of EMS. In this case, endogeneity problems and therefore biased and inconsistent parameter estimates in regressions of green management on green technology are possible.

4.2 Unobserved Firm Heterogeneity

We argue that technological environmental innovations and green management measures are accompanied by specific unobserved capabilities and knowledge. We consider this unobserved firm heterogeneity, i.e., unobserved firm characteristics that simultaneously influence green management measures and technological environmental innovations, to be an important source of endogeneity problems.

The resource-based view of the firm emphasizes the importance of firms' internal resources. Resources which are valuable, rare, and difficult to imitate or to substitute, are fundamental to attain competitive advantages (Barney, 1991) and therefore key for innovative activity (Galende and de la Fuente, 2003). Lately the focus lies on firms' knowledge and information based assets (Galende and de la Fuente, 2003; Rugman and Verbeke, 2000). This emphasis on learning links the resource-based view with evolutionary theory which highlights organizational routines based on tacit knowledge. Lazonick (2005: 34) points out that "[...] the essence of the innovative firm is the organizational integration of a skill base that can engage in collective and cumulative learning".

Technological environmental innovations are likely to be preceded by the establishment of useful organizational routines and tacit knowledge related to environmental issues. These organizational routines are probably also determinants of green management measures such as certified EMS or life cycle assessment activities. These capabilities are defined as “[...] the coordinating mechanisms that enable the most efficient and competitive use of the firm's assets - whether tangible or intangible” (Sharma and Vredenburg, 1998: 735). Intangible assets (e.g., reputation, learning processes) are more likely to lead to innovations and competitive advantages since they are more likely to be rare and difficult to copy than tangible ones (e.g., financial resources). Since these firm characteristics are not directly observable, they are difficult to include in cross-sectional regressions of green technology on green management. Due to this specific endogeneity problem, the corresponding parameter estimates could therefore be biased and inconsistent.

5 Econometric Analysis of the Effect of Green Technology on Green Management

In this section, we empirically explore the structural reverse causality. In other words, we test (contrary to former studies) the reverse hypothesis that technological environmental innovations have an influence on green management measures.

5.1 Data and Variables

The data for our empirical analysis were collected by means of a questionnaire-based telephone survey at the Centre for European Economic Research (ZEW) in Mannheim, Germany, in summer/autumn 2003. The questionnaire was developed after having conducted six case studies with German companies from the manufacturing sector and pretested beforehand. As discussed above, the stratified random sample was drawn from the population of all German manufacturing companies with 50 or more employees. 2998 addresses were drawn considering two classes of firm size (less than 200 and at least 200 employees), two regions (Western and Eastern Germany), and eleven industries. The corresponding corporations were notified in advance by mail of the forthcoming survey. The interviewees were the responsible production managers (R&D Manager, Environmental Manager, General Manager) which the case studies showed to be the most competent respondents for the survey.

Of the 2511 targeted companies, 112 could not be reached, 1811 refused to participate, and 588 participated in the survey. Thus, of the 2399 companies reached, 24.5% participated in the survey. This is a fairly typical participation rate for firm-related telephone surveys in Germany. Statistical tests showed that the stratified groups (firm size, region, industry) in the sample did not deviate significantly from the shares in the population (two-tailed tests, 10% level of significance). Overall, 368 of the 588 companies were included in the econometric analysis. We excluded firms founded in the years 2002 or 2003 and those with incomplete data for an examined variable.

Regarding certified EMS and the other green management measures, all firms were asked in the questionnaire whether they currently applied the following measures: Certification according to ISO 14001 or according to EMAS of at least one facility, environmental labeling of a product, life cycle assessment activities, and waste disposal measures. The corresponding dummy variables ("ISO 14001", "EMAS", "Eco-label", "Life cycle assessment", "Waste disposal") take the value one if the company applied the measures in 2003 and serve as dependent variables in the econometric analysis. Regarding EMS, we also analyze an additional dependent dummy variable ("ISO-EMAS") that takes the value one if the company was certified according to either ISO 14001 or EMAS or to both.

The main explanatory variables refer to the technological environmental innovations.

The appropriate dummy variables ("Environmental product innovation", "Environmental process innovation") take the value one if the company realized at least one of the corresponding technological environmental innovations between 2001 and 2003. As control variables we also examine conventional product and process innovations. The appropriate dummy variables ("Conventional product innovation", "Conventional process innovation") take the value one if the company realized at least one of the corresponding technological conventional innovations between 2001 and 2003. The realization of a conventional product or process innovation refers to an activity that does not contribute to the avoidance or reduction of environmental burden. In other words, technological environmental innovations are not a subset of technological conventional innovations.

Based on existing studies showing the importance of firm size and the significance of management perception of environmental issues (e.g., Halkos and Evangelinos, 2002) and more generally market pull and technology push for environmental innovations (Rennings, 2000), we include several additional control variables in the econometric analysis. We include dummy variables for R&D activities ("R&D"), firm exports ("Exports"), the sale of products on the environmental market ("Environmental market"), the importance of quality ("Quality important"), customer care ("Customer important"), innovation ("Innovation important"), or the environment ("Environment important") as competition factors, the certification according to ISO 9001 ("ISO 9001"), as well as the share of sales for industrial customers ("Industrial customer"), the natural logarithm of the firm's age ("Age") and the natural logarithm of the number of employees ("Size"). One important explanatory variable, namely environmental regulatory stringency, could not be included in our analysis. Appropriate indicators for this regulatory stringency are very difficult to determine and therefore seldom used in cross-sectional data. However, we include as further control variables some sector dummies which approximate variation of environmental regulatory stringency in different industry sectors, although the corresponding parameter estimates are not displayed in the following for brevity.

5.2 Econometric Approach

Since the dependent variables are dummy variables (i.e., binary variables), we apply probit models. In a first step, we analyze univariate probit models, separately for all examined green management activities (i.e., for “ISO 14001”, “EMAS”, “ISO-EMAS”, “Eco-label”, “Life cycle assessment”, and “Waste disposal”). However, being aware of the potentially strong relationships between these green management measures, we check the robustness of the estimation results in the univariate probit models through the estimation of multivariate probit models (e.g., Greene, 2000). Besides the estimation of the parameters of the explanatory variables, these models consider the estimation of correlation coefficients between two or more dependent dummy variables in the corresponding stochastic components of the underlying latent variables. If these correlations were neglected, biased and inconsistent parameter estimates would be possible.

While the estimation of uni- and bivariate probit models is straightforward and feasible with all standard software packages, the estimation of multivariate probit models with more than two dependent variables is more complex and requires the inclusion of simulators in the maximum likelihood method. This simulated maximum likelihood estimation (incorporating the so-called GHK simulator, e.g., Ziegler and Eymann, 2001) was recently included in the statistics software STATA which we used for all estimations. Furthermore, we have considered the so-called robust estimations of the standard deviation of the parameter estimates (White, 1982). We refrain from displaying the estimated correlation coefficients in the multivariate probit models for brevity.

5.3 Empirical Results

Table 1 reports the descriptive statistics for the dependent variables and the main explanatory variables. According to this, almost a fourth of the analyzed 368 companies had an ISO 14001 certification in 2003, whereas less than 8% were EMAS certified. We checked and corrected the variable EMAS certification of the surveyed firms (http://www.emas-register.de/startseite.aspx) by the end of 2005. Of the 22 certified firms in the original sample, only 10 remained certified. Due to the limited numbers of EMAS certified companies in the sample, we consider ISO 14001 to be a more reliable indicator for EMS certification. Most of the EMAS certified firms (76%) were also ISO 14001 certified.

Of the examined 368 companies, 37.2% realized an environmental product innovation. In contrast, the number of firms realizing environmental process innovations between 2001 and 2003 is much higher with 71.2% of companies. A majority of companies (64.4%) realized a conventional product innovation. This is almost twice as many as the number of firms that realized an environmental product innovation. Finally, 69.6% realized a conventional process innovation.

In a first step, we conducted a univariate probit analysis regarding the dependent variables "ISO 14001", "EMAS", and "ISO-EMAS". According to Table 2, environmental process and conventional product innovations have a positive effect on the ISO 14001 certification at the 10% level of significance. Also the environment as an important competition factor has a significantly positive influence. Of the control variables, firm size and ISO 9001 certification increases the probability of ISO 14001 certification. EMAS certification is significantly positively affected by environmental product innovations. In contrast, conventional product innovations have a negative effect. This points to a marked difference between conventional and environmental product innovators with regard to the EMAS certification. Finally, environmental process innovations have a positive influence on “ISO-EMAS” at the 5% level of significance.

According to Table 3, an effect of environmental and conventional innovations can mainly be found for life cycle assessment activities. This measure is influenced by environmental product innovations and conventional process innovations at the 5% level of significance. However, conventional product innovations have a negative influence as in the case of EMAS and ISO 14001 certification. Again conventional and environmental product innovators seem to differ. Whereas environmental product innovations have a positive influence on “Waste disposal” at the 10% level of significance, no significant effect of technological environmental innovations on “Eco-label” can be found. For this variable only the share of sales for industrial customers and firm size has a weakly significant effect, showing the plausible result that the less industry or the more end consumers a firm has and the larger (and therefore more visible) a corporation, the more likely environmental labeling of products is performed.

To determine whether the influence of technological environmental innovations on green management measures hold, considering that they could be correlated, we have conducted multivariate probit analyses. According to Table 4 and Table 5, the effects of the explanatory variables on the various EMS certifications and the three other green management measures (“Eco-label”, “Life cycle assessment”, and “Waste disposal”) remain stable or are amplified as in the case of ISO 9001 certification on “EMAS” if bivariate probit models and environmental product innovations on “Life cycle assessment” if multivariate probit models are estimated.

We interpret these empirical results as a further indicator that the causal relationship between green management and green technology is not clear. According to our results and the results in Ziegler and Rennings (2004) and Rehfeld *et al.* (2006) who find a positive effect of green management measures on future environmental product or process innovations, a positive relationship exists. However, the parameter estimates which apparently imply significant effects should be interpreted with caution.

6 Conclusions

This paper analyzes the causal relationship between green management measures and technological environmental innovations. We argue that the significantly positive effects of green management on corporate environmental performance in former econometric studies could be influenced by endogeneity problems due to structural reverse causality and/or unobserved firm heterogeneity. To support these endogeneity hypotheses, the paper refers to evolutionary theory and the resource-based view of the firm. These imply that technological environmental innovations could actually influence green management and that unobserved intangible corporate environmental capabilities could simultaneously influence green management and green technology. As a consequence, the apparently significant effects of green technology on green management or, reversely, of green management on green technology could be influenced by biased and inconsistent parameter estimates.

To further support the structural reverse causality hypothesis, the paper empirically explores, contrary to existing studies, the effect of technological environmental innovations on green management measures. Firms which already have realized such innovations in the past are more likely to possess environmental capabilities in having overcome management barriers such as the lack of finance or know-how at least once before. The econometric analyses with uni- and multivariate probit models imply a significantly positive effect of environmental process innovations on certified EMS and a significantly positive impact of environmental product innovations on life cycle assessment activities. We interpret these empirical results as a further indicator that the direction of causality between green management and green technology is not clear. A positive relationship seems to exist, but the derived significant effects in this study as well as in studies analyzing the impact of green management on environmental performance should be interpreted with caution.

Our results are of high practical relevance. The inconclusive results suggest that the contribution of non-mandatory approaches in environmental policy encouraging green management to foster corporate environmental performance is not fully clear. Several European countries including the EU promote voluntary green management measures and aim at supplementing such non-mandatory approaches to traditional mandatory command and control regulations as well as market based instruments such as green taxes. However, if measures such as certified EMS, environmental labeling of products, life cycle assessment activities, or waste disposal measures as well as green technology activities were simultaneously more likely to be realized by already environmentally active firms, green management measures would not need separate public support. It is particularly questionable whether such non-mandatory approaches could replace mandatory regulations. However, we do not argue that green management measures cannot be conducive to environmental performance. We do question the assumption that they do so in general, though.

It should be emphasized that these conclusions are more or less preliminary. Along with Börsch-Supan and Köke (2002), we conclude that firm-level panel data, which are not available for technological environmental innovations yet, are a necessary condition to solve the endogeneity problems in econometric studies which regress green technology on green management. Unlike cross-sectional data, panel data can control for unobserved firm characteristics and can provide valid instruments for green management measures if their effect on green technology is analyzed. Such panel data studies could therefore be an appropriate basis for robust conclusions with regard to voluntary green management measures as a non-mandatory approach in environmental policy.

7 References

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

Anton WRQ, Deltas G, Khanna M. 2004. Incentives for Environmental Self-Regulation and Implications for Environmental Performance. *Journal of Environmental Economics and Management* **48**: 632-654.

Arora S, Cason TN. 1995. An Experiment in Voluntary Environmental Regulation: Participation in EPA's 33/50 Program. *Journal of Environmental Economics and Management* **28**: 271-286.

Arora S, Cason TN. 1996. Why do Firms Volunteer to Exceed Environmental Regulations? Understanding Participation in EPA's 33/50 Program. *Land Economics* **72**: 413-432.

Barney JB. 1991. Firm Resources and Sustained Competitive Advantage. *Journal of Management* **17**: 99-120.

Behrens C, Heck A, Wirth S. 2003. Analyse der Anreiz- und Belohnungsregelungen für EMAS-Organisationen auf europäischer Ebene und Bewertung hinsichtlich der nationalen Umsetzbarkeit. Umweltbundesamt: Berlin.

Biondi V, Frey M, Iraldo F. 2000. Environmental Management Systems and SMEs. Motivations, Opportunities and Barriers Related to EMAS and ISO 14001 Implementation. *GMI* **29**: 55-69.

Börsch-Supan A, Köke J. 2002. An Applied Econometricians' View of Empirical Corporate Governance Studies. *German Economic Review* **3**: 295-326.

Coglianese C, Nash J (eds.). 2001. *Regulating from the Inside: Can Environmental Management Systems Achieve Policy Goals?* RFF Press: Washington, D.C.

Dahlström K, Howes C, Leinster P, Skea J. 2003. Environmental Management Systems and Company Performance: Assessing the Case for Extending Risk-based Regulation. *European Environment* **13**: 187-203.

Dasgupta S, Hettig H, Wheeler D. 2000. What Improves Environmental Compliance? Evidence from Mexican Industry. *Journal of Environmental Economics and Management* **39**: 39-66.

DeCanio SJ, Watkins WE. 1998. Investment in Energy Efficiency: Do the Characteristics of Firms Matter? *Review of Economics and Statistics* **80**: 95-107.

Der Grüne Punkt. 2005. The Letters of the Law. 26.1.2006. "The Letters of the Law." Retrieved 06/06/2006, from http://www.gruener-punkt.de/Legal_foundations.

EC. 2001. Green Paper on Integrated Product Policy. European Commission: Brussels.

Elster J. 1983. *Explaining Technical Change*. Cambridge University Press: Cambridge.

EMAS Helpdesk. 2005. EMAS Statistics Organisations and Sites. "EMAS Statistics Organisations and Sites." Retrieved 06/06/2006, from http://europa.eu.int/comm/environment/emas/registration/sites_en.htm.

EU Council. 2005. Advancing Better Regulation in Europe - UK/Austrian/Finnish Presidency paper. Council of the European Union: Brussels.

Frondel M, Horbach J, Rennings K. 2004. What Triggers Environmental Management and Innovation? Empirical Evidence for Germany, *Discussion Paper No. 15*. RWI: Essen.

Frondel M, Horbach J, Rennings K. 2006. End-of-Pipe or Cleaner Production Measures? An Empirical Comparison of Abatement Decisions Across OECD Countries. *Business Strategy and the Environment: forthcoming.*

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

Greene WH. 2000. *Econometric Analysis* (fourth edition, international ed.). Prentice-Hall International: London.

Gunningham N, Sinclair D. 1998. New Generation Environmental Policy: Environmental Management Systems and Regulatory Reform. *Melbourne University Law Review* **22**: 592-616.

Halkos GE, Evangelinos KI. 2002. Determinants of Environmental Management Systems Standards Implementation: Evidence from Greek Industry. *Business Strategy and the Environment* **11**: 360-375.

ISO. 2005. The ISO Survey of Certifications - 2004. International Organization for Standardization: Geneva.

Jaffe AB, Newell RG, Stavins RN. 2002. Environmental Policy and Technological Change. *Environmental and Resource Economics* **22**: 41-69.

Johnstone N. 2001. *The Firm, the Environment, and Public Policy. Final Report of the Eco-Efficiency Project*. OECD Environment Directorate, Environment Policy Committee, Working Party on National Environmental Policy: Paris.

Johnstone N, Scapecchi P, Serravalle C. 2005. Environmental Policy and Corporate Behaviour: Background Report and Overview of the Data, *OECD/EPA/Environment Canada Conference on 'Public Environmental Policy and the Private Firm'*. OECD: Washington, D.C.

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

Khanna M, Damon LA. 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.

King AA, Lenox MJ. 2000. Industry Self-Regulation Without Sanctions: The Chemical Industry's Responsible Care Program. *Academy of Management Journal* **43**: 698-716.

Lam A. 2005. Organizational Innovation. In *The Oxford Handbook of Innovation*, Fagerberg J, Mowery DC, Nelson RR (eds.). Oxford University Press: Oxford. 115-147 pp.

Lazonick W. 2005. The Innovative Firm. In *The Oxford Handbook of Innovation*, Fagerberg J, Mowery DC, Nelson RR (eds.). Oxford University Press: Oxford. 29-55 pp.

Lenox MJ, Nash J. 2003. Industry Self-Regulation and Adverse Selection: A Comparison Across Four Trade Association Programs. *Business Strategy and the Environment* **12**: 343-356.

Melnyk SA, Sroufe RP, Calantone R. 2003. Assessing the Impact of Environmental Management Systems on Corporate and Environmental Performance. *Journal of Operations Management* **21**: 329-351.

Nakamura M, Takahashi T, Vertinsky I. 2001. Why Japanese Firms Choose to Certify: A Study of Managerial Responses to Environmental Issues. *Journal of Environmental Economics and Management* **42**: 23-52.

Nelson RR. 1991. Why Do Firms Differ, and How Does it Matter? *Strategic Management Journal* **12**: 61-74.

Nelson RR, Winter SG. 2002. Evolutionary Theorizing in Economics. *Journal of Economic Perspectives* **16**: 23-46.

OECD, Eurostat. 1997. Oslo Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data. Organization for Economic Co-Operation and Development: Paris.

Potoski M, Prakash A. 2005. Covenants with Weak Swords: ISO 14001 and Facilities' Environmental Performance. *Journal of Policy Analysis and Management* **24**: 745-769.

Rehfeld K-M, Rennings K, Ziegler A. 2006. Integrated Product Policy and Environmental Product Innovations - An Empirical Analysis. *Ecological Economics: forthcoming*

Rennings K. 2000. Redefining Innovation — Eco-Innovation Research and the Contribution from Ecological Economics. *Ecological Economics* **32**: 319-332.

Rennings K, Ziegler A, Ankele K, Hoffmann E. 2006. The Influence of Different Characteristics of the EU Environmental Management and Auditing Scheme on Technical Environmental Innovations and Economic Performance. *Ecological Economics* **57**: 45-59.

Rugman AM, Verbeke A. 2000. Six Cases of Corporate Strategic Responses to Environmental Regulation. *European Management Journal* **18**: 377-385.

Sharma S, Vredenburg H. 1998. Proactive Corporate Environmental Strategy and the Development of Competitively Valuable Organizational Capabilities. *Strategic Management Journal* **19**: 729-753.

Umweltbundesamt U. 2003. A Guide to Environmental Institutions in Germany. Federal Environmental Agency: Berlin.

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

Ziegler A, Eymann A. 2001. Zur Simulated Maximum-Likelihood-Schätzung von Mehrperioden-Mehralternativen-Probitmodellen. *Allgemeines Statistisches Archiv* **85**: 319-342.

Ziegler A, Rennings K. 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: Tables

Table 1: Descriptive statistics of main variables (number of firms = 368)

Dummy Variables	1	0
ISO 14001	24.2%	75.8%
EMAS	7.9%	92.1%
ISO-EMAS	26.1%	73.9%
Eco-label	8.4%	91.6%
Life cycle assessment	16.0%	84.0%
Waste disposal	37.8%	62.2%
Environmental product innovation	37.2%	62.8%
Environmental process innovation	71.2%	28.8%
Conventional product innovation	64.4%	35.6%
Conventional process innovation	69.6%	30.4%

Table 2: Univariate probit analysis: "ISO 14001", "EMAS", "ISO-EMAS"

Explanatory Variables	ISO 14001	EMAS	ISO-EMAS
Constant	-3.04^{***}	-2.67^{***}	-2.66^{***}
Environmental product innovation	0.13	0.39^{*}	0.14
Environmental process innovation	0.40^{*}	0.32	0.44^{**}
Conventional product innovation	-0.34^{*}	-0.68^{***}	-0.40^{**}
Conventional process innovation	0.24	0.66^{***}	0.25
R&D	0.30	0.48	0.10
Exports	-0.20	0.09	-0.08
Industrial customer	0.43^{**}	0.12	0.34^{*}
Environmental market	0.03	-0.66^{**}	-0.01
Quality important	-0.00	0.39	0.07
Customer important	-0.03	0.10	-0.05
Innovation important	0.06	-0.15	0.11
Environment important	0.43^{**}	-0.07	0.36^{*}
ISO 9001	0.80^{***}	0.48^{*}	0.69^{***}
Age	-0.09	0.02	-0.05
Size	0.33^{***}	0.00	0.29^{***}

Remarks: ***/**/* means that the null hypothesis that the appropriate parameter is zero can be rejected at the 1%/5%/10% level of significance (according to the corresponding two-tailed test). Number of firms = 368.

Table 3: Univariate probit analysis: "Eco-label", "Life cycle assessment", "Waste disposal"

Explanatory Variables	Eco-label	Life cycle assessment	Waste Disposal
Constant	-2.93***	-5.19***	0.27
Environmental product innovation	0.13	0.46**	0.28*
Environmental process innovation	0.38	0.36	-0.00
Conventional product innovation	-0.02	-0.44**	-0.08
Conventional process innovation	0.14	0.73***	0.00
R&D	-0.16	0.22	0.06
Exports	0.62	0.10	-0.07
Industrial customer	-0.42*	0.09	-0.19
Environmental market	0.04	0.24	0.30
Quality important	-0.28	0.19	0.23
Customer important	-0.30	0.67	-0.07
Innovation important	0.26	-0.36*	-0.03
Environment important	0.20	0.04	0.08
ISO 9001	0.17	-0.17	-0.03
Age	-0.03	-0.01	-0.12**
Size	0.18*	0.52***	-0.01

Remarks: ***/**/* means that the null hypothesis, that the appropriate parameter is zero, can be rejected at the 1%/5%/10% level of significance (according to the corresponding two-tailed test). Number of companies = 368.

Table 4: Bivariate probit analysis: "ISO 14001", "EMAS"

Explanatory Variables	ISO 14001	EMAS
Constant	-3.02***	-2.60***
Environmental product innovation	0.11	0.41*
Environmental process innovation	0.38*	0.43*
Conventional product innovation	-0.35*	-0.70***
Conventional process innovation	0.25	0.70***
R&D	0.27	0.33
Exports	-0.17	0.25
Industrial customer	0.38**	0.17
Environmental market	0.08	-0.65**
Quality important	0.02	0.53*
Customer important	-0.03	0.13
Innovation important	0.05	-0.07
Environment important	0.43**	-0.02
ISO 9001	0.79***	0.53**
Age	-0.07	0.02
Size	0.32***	-0.06

Remarks: ***/**/* means that the null hypothesis, that the appropriate parameter is zero, can be rejected at the 1%/5%/10% level of significance (according to the corresponding two-tailed test). Number of companies = 368.

Table 5: Multivariate probit analysis: "ISO-EMAS", "Eco-label", "Life cycle assessment", "Waste disposal"

Explanatory Variables	ISO-EMAS	Eco-label	Life cycle assessment	Waste disposal
Constant	-2.69***	-2.91***	-5.22***	0.28
Environmental product innovation	0.15	0.08	0.48***	0.28*
Environmental process innovation	0.46**	0.39	0.38	-0.01
Conventional product innovation	-0.39**	-0.00	-0.42**	-0.08
Conventional process innovation	0.24	0.15	0.74***	0.00
R&D	0.13	-0.19	0.18	0.06
Exports	-0.09	0.55	0.10	-0.06
Industrial customer	0.35*	-0.41*	0.10	-0.19
Environmental market	-0.03	0.04	0.24	0.29
Quality important	0.09	-0.29	0.21	0.23
Customer important	-0.07	-0.27	0.69*	-0.07
Innovation important	0.10	0.24	-0.38*	-0.04
Environment important	0.37*	0.22	0.05	0.08
ISO 9001	0.70***	0.18	-0.16	-0.03
Age	-0.05	-0.03	-0.02	-0.12**
Size	0.29***	0.18*	0.52***	-0.01

Remarks: ***/**/* means that the null hypothesis, that the appropriate parameter is zero, can be rejected at the 1%/5%/10% level of significance (according to the corresponding two-tailed test). Number of companies = 368.