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Determinants of environmental product and process innovations: New evidence on the basis of European panel data

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Determinants of environmental product and process innovations: New evidence on the basis of European panel data

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Abstract

This paper empirically examines the determinants of corporate environmental product and process innovations. In contrast to previous studies, we use panel data from the ASSET4 and Worldscope databases for firms from 25 European countries between 2004 and 2017. This allows us to control for unobserved heterogeneity and time effects. Our fixed and random effects estimations in binary logit models reveal the relevance of this flexible panel data analysis. The estimation results imply positive effects especially of environmental training programs for employees and implemented environmental organizational measures on environmental process innovations. Interestingly, certified environmental management systems (EMS), certified quality management systems, and market pull factors seem to play no role for environmental process innovations, but rather for environmental product innovations. The latter are additionally affected by several technological push factors. This suggests public support of such non-mandatory approaches in order to foster environmental product innovations.

Keywords: Environmental product and process innovations; technological push and market pull factors; organizational measures; panel data; European firms

JEL: Q55, O32, O33, C23, C25

1. Introduction

Policymakers and researchers agree that only a mixture of different adaptation and mitigation activities embedded in a supportive and appropriate policy framework can achieve (inter-) national climate policy goals and sustainable development. Besides, for example, behavior changes of individuals or (innovative) well-targeted investments, technological environmental innovations¹ at the firm level are seen as crucial component, as they can significantly contribute to the reduction of firms' negative environmental externalities (e.g. Del Rio et al., 2016; Horbach and Reif, 2018; Horbach et al., 2012; IPCC, 2018; Rennings, 2000; UNFCCC, 2015).

However, even modest goals require substantial (environmental) innovations (e.g. Rennings, 2000). Moreover, all kinds of innovations have in common that they lead to positive externalities, as society benefits from technological and knowledge spillovers, but costs are mainly borne by a single firm. This market failure can consequently lead to fewer innovation activities and innovations than desired or necessary (e.g. Ziegler, 2015). Environmental innovations lead to further positive externalities, as they not only contribute to the technological progress of, for example, production processes or products, but also reduce their environmental impact, which leads to a “double dividend” (e.g. Kammerer, 2009; Ziegler, 2015) or a “win-win” situation (e.g. Horbach, 2008; Demirel and Kesidou, 2011). While policy instruments designed to promote innovations in general will probably also positively affect environmental innovations, this often called “double externality problem” (Rennings, 2000) is the main argument to call for a coordinated environmental and innovation policy as well as policy instruments specifically designed to foster environmental innovations (e.g. Del Rio et al., 2016). In order to identify appropriate policy measures, such as taxes or command-and-control measures, or soft instruments to incentivize voluntary corporate activities, it is therefore crucial to identify and understand the determinants of environmental innovations.

Against this background, one main strand of literature in the research field of environmental innovations refers to the empirical identification of external and internal factors affecting firm decisions to conduct environmental innovations (e.g. Barbieri et al., 2016).² Several reviews summarizing the empirical findings show that there is an agreement that firm-internal techno-

¹ Other studies also use the terms “eco-innovations” or “green innovations”. We follow previous studies which use these terms synonymously (e.g. Horbach et al., 2012; Horbach and Reif, 2018), but mainly use the term “environmental innovations”, as it is used most frequently (e.g. Angelo et al., 2012; Del Rio et al., 2016).

² The consideration of economic and environmental effects or policy inducement represent other main paths in this research field (e.g. Barbieri et al., 2012). Another strand of literature, for example, considers the relationship between environmental innovations and financial performance (e.g. Ghisetti, 2018) and thus refers to empirical examinations of the Porter hypothesis (Porter and van der Linde, 1995).

logical push factors, such as research and development (R&D) activities, environmental management systems (EMS), and other organizational measures within firms, such as life-cycle assessments or waste disposal measures as well as external regulatory measures are key drivers of environmental innovations (e.g. Bossle et al., 2016; Del Rio et al., 2016; Hojnik and Ruzzier, 2016). However, the opinions and results concerning the role of external market or demand pull factors are diverging and require further exploration (e.g. Del Rio et al., 2016; Hojnik and Ruzzier, 2016). They also show that determinants vary with respect to different types of environmental innovations, such as environmental process versus product innovations (e.g. Ziegler, 2015) or across different types of environmental process innovations (e.g. Horbach et al., 2012).

However, these reviews also reveal that the empirical analyses are mostly based on cross-sectional (survey) data (e.g. Frondel et al., 2008; Rehfeld et al., 2007; Kammerer, 2009; Horbach et al., 2012; Ziegler, 2015), which naturally do neither allow to control for unobserved heterogeneity or time effects nor to capture the dynamic characteristics of innovations (e.g. to include lagged explanatory variables). Consequently, endogeneity issues due to reverse causality or omitted variables could (at least partly) drive the results of the studies, as discussed, for example, by Wagner (2007, 2008) and Ziegler and Nogareda (2009). These problems could be overcome by the consideration of panel datasets with observations over a long time horizon, and specific econometric approaches for panel data, such as random effects or fixed effects estimations. Moreover, the analysis of panel data would allow to analyze potential path dependencies of environmental innovations, meaning that previous environmental innovators are also innovators in the future (i.e. “innovation breeds innovation”, see Horbach, 2008). Consequently, there has been a call for panel data analyses that allow to examine long-term developments, path dependencies, and to control for unobserved heterogeneity (e.g. Horbach, 2008; Ziegler, 2015; Del Rio et al., 2016).

Some of the very few extant studies providing results of panel data analyses are based on industrial level data (e.g. Brunnermeier and Cohen, 2003; Carrión-Flores and Innes, 2010; Jaffe and Palmer, 1997), which obviously cannot directly analyze environmental innovations at the firm level. Additionally, the study by Jaffe and Palmer (1997), who analyze panel data for the US manufacturing sector, has been criticized for using general patent data, which do not necessarily capture environmental innovations (e.g. Brunnermeier and Cohen, 2003; Rennings et al., 2006). Besides, patents are often seen as insufficient measure for innovations, as it is not guaranteed that they will be implemented (e.g. Rennings et al., 2006; Ziegler, 2015). The latter argument would also apply to the studies of Brunnermeier and Cohen (2003) or Carrión-Flores

and Innes (2010) that both consider environmental patent data as proxy for environmental innovations. These issues can be partly solved by Horbach (2008) or Demirel and Kesidou (2011). Horbach (2008) analyzes survey panel data on German firms from the Institute of Employment Research for the years 2001 and 2004, which measures environmental innovations by a variables indicating whether a firm supplies environmental goods (and services) and has improved or developed a new product two preceding years of the survey. However, due to too few observations, Horbach (2008) can solely apply random effects estimations, but not fixed effects estimations. Demirel and Kesidou (2011) examine corporate investments into end-of-pipeline pollution control technologies, integrated cleaner production technologies, and environmental R&D as measures for environmental innovations. They consider panel data for the years of 2005 and 2006 and regress dependent variables from the year 2006 on lagged explanatory variables (i.e. from the year 2005). However, they do not apply specific panel data techniques, such as random effects or fixed effects estimations. Hence, both studies are based on very short time horizons and it is thus not possible to consider long-term time effects.

Additionally, most studies focus on single (Western European) countries³, and only a few studies are based on data for two or more countries (e.g. Wagner, 2008; Triguero et al., 2013; Ghisetti et al., 2015; Horbach et al., 2013; Horbach, 2016). In fact, yet there is no study conducting a panel data analyses for several countries. Accordingly, there is a lack of cross-country (Horbach, 2016) and panel data studies (e.g. Del Rio et al., 2016).

Against this background, this paper aims to contribute to the existing literature in three directions. First, we analyze panel data derived from the databases ASSET4 and Worldscope, which we have accessed via Thomson Reuters Datastream. In contrast to previous studies, our dataset comprises observations over a long time period, i.e. from 2004 to 2017, which enables us to apply sophisticated panel data approaches and to especially control for unobserved heterogeneity and time effects (e.g. through the inclusion of time dummies and lagged explanatory variables). Secondly, by considering data from ASSET4 and Worldscope, we thus analyze data sources, which has not been used to answer these kinds of research questions.⁴ We thereby test

³ For example, Rennings et al. (2006), Frondel et al. (2007), Rehfeld et al., 2007, Wagner (2007), Horbach et al. (2012), Ziegler (2015) focus on Germany, Antonioli et al. (2013), Cainelli and Mazzanti (2013), Borghesi et al. (2015), Antonioli and Mazzanti (2017) analyze data on Italian firms, De Marchi (2012) considers Spain, and Demirel and Kesidou (2011), Kesidou and Demirel (2012) firms from the UK. For a more detailed overview see Del Rio et al. (2016).

⁴ Previous empirical studies are often based on data from the Community Innovation Survey (e.g. Horbach et al., 2012; Horbach et al., 2013; Cainelli and Mazzanti, 2013; Borghesi et al., 2015; Ghisetti et al., 2015; Horbach et al., 2016), the Mannheim Innovation Panel (e.g. Horbach, 2008), or data from self-conducted surveys (e.g. Rennings et al., 2006; Rehfeld et al., 2007; Wagner, 2007; Kammerer, 2009; Antonioli et al., 2013; Ziegler, 2015; Antonioli and Mazzanti, 2017).

the validity of the previous results on the basis of a “new” data source, which might be the basis for research paths in this area. Finally, our data covers data on firms from 25 European countries, which offers us the opportunity to examine country or regional differences.

Our fixed and random effects estimations in binary logit models reveal the relevance of this flexible panel data analysis. The estimation results imply positive effects especially of technological push factors, such as environmental training programs for employees or environmental organizational measures, on environmental process innovations. Interestingly, certified EMS, certified quality management systems, and market pull factors seem to play no role for environmental process innovations. As also reported by previous studies, our results clearly indicate that environmental process and product innovations are driven by different factors. Particularly, EMS, certified quality management systems, and market pull factors, but also several technological push factors are relevant for environmental product innovations. Hence, it is important to distinguish between these two innovation types in empirical analyses. Further, our results suggest that soft policy instruments to foster voluntary management measures or the adoption of labeling schemes (e.g. Rehfeld et al., 2007) are still appropriate. However, in order to additionally strengthen environmental process innovations, it is necessary to focus on the implementation of specific measures instead of their pure certification.

The remainder of the paper is organized as follows: Section 2 defines (environmental) innovations and presents the conceptual framework as well as the empirical results of previous studies regarding determinants of environmental product and process innovations. Section 3 describes the dataset and the variables in our panel data analysis. Section 4 reports and discusses the estimation results. The final section 5 draws conclusions and gives an outlook about the next steps to be taken.

2. Definitions and conceptual framework

2.1 Definitions

According to the most recent version of the Oslo Manual (OECD/Eurostat, 2018), a “business innovation is a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm.” (OECD/Eurostat, 2018, p. 68). Thus, this new definition is a simplified version of the previous definition from 2005 (OECD/Eurostat, 2005), which distinguished between product, process, organizational, and marketing innovations and has been the conceptual basis for several studies on environmental innovations (e.g.

Kammerer, 2009; Horbach et al., 2012; Ziegler, 2015).⁵ In the revised version, organizational and marketing innovations have been subsumed under the new categories “administration and management” and “marketing sales”, respectively, which are both understood as business processes. Other business processes are summarized into the categories “production of goods or services”, “distribution and logistics”, “information and communications systems”, and “product and business process development”. Accordingly, a business process innovation refers to these fields and comprises “a new or improved business process for one or more business functions that differs significantly from the firm’s previous business processes and that has been brought into use by the firm.” (OECD, 2018, p. 72). Similarly, “[a] product innovation is a new or improved good or service that differs significantly from the firm’s previous goods or services and that has been introduced on the market.” (OECD, 2018, p. 70). Hence, though the definitions have slightly changed, the distinction between product and process innovations is still crucial, as it has been emphasized by earlier studies that refer to previous definitions (e.g. Horbach et al., 2012; Ziegler, 2015). For example, product innovations are rather seen as mean to introduce product differentiations or driven by demand factors, whereas process innovations often rather have the aim to reduce costs, increase energy efficiency, or comply with regulatory requirements with rather little benefit for the customer (Ziegler, 2015; Del Rio et al., 2016). However, the definitions of product and process innovations have in common that both require that they have already been implemented by the firm. That is, goods have to be introduced to the market and processes have to be actually used by the company. However, both only have to be new to the firm, i.e. they do not need to be new to the market or other firms (e.g. Horbach et al., 2012). Consequently, we follow previous studies (e.g. Ziegler and Nogareda 2009; Ziegler 2015) and do not consider (environmental) patents (e.g. Brunnermeier and Cohen, 2003), which might have not been implemented by the firm yet and thus could be a problematic proxy for (environmental) innovations.

As we see that the new definition is similar to the previous definition, we can still define environmental innovations in line with previous studies on this issue, which is usually based on the former definition of the OECD from the year 2005 (e.g. Kammerer, 2009; Horbach et al., 2012; Ziegler, 2015). For example, several studies (e.g. Horbach et al., 2012; Horbach and Reif, 2018) refer to the definition developed by Kemp and Pearson (2008, p.7): “Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and

⁵ Earlier studies refer to the second edition of the Oslo Manual from 1997 (e.g. Rennings et al., 2006; Rehfeld et al., 2007; Wagner, 2008; Ziegler and Nogareda, 2009).

which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.”. Although there is no common definition yet (e.g. Hojnik and Ruzzier, 2016), all definitions have in common that environmental innovations reduce the environmental impact of related products or activities (e.g. Del Rio et al., 2016) and use resources more efficiently (e.g. Hojnik and Ruzzier, 2016), regardless of whether the positive environmental impact was intended or not (e.g. Horbach et al., 2012).

2.2 Conceptual framework

Yet, there exists no uniform theoretical framework for environmental innovations and their determinants (e.g. Del Rio et. 2016) and the framework for general innovations is not sufficient for environmental innovations (e.g. Rennings, 2000). Instead, the theoretical argumentation is usually derived from several theoretical concepts, such as general innovation theory, environmental economics, (neo-) institutional theory, resource-based theory, stakeholder theory, and evolutionary approaches (e.g. Rennings, 2000; Hojnik and Ruzzier, 2016).

Previous studies often consider a simple conceptual framework, which distinguishes between firm-internal and firm-external factors (e.g. Del Rio, 2009; Borghesi et al., 2015; Bossle et al., 2016; Del Rio et al., 2016) or four categories of determinants, namely technological push or supply side factors, market pull or demand side factors, regulatory push/pull factors, and further firm-specific factors (e.g. Rennings, 2000; Horbach et al., 2012). Technological push as well as market pull factors are also relevant for innovations in general (e.g. Pavitt, 1984; Rennings, 2000), but the former are rather important for the initial phase and the latter for the diffusion phase (e.g. Pavitt, 1984; Rehfeld et al., 2007).

Accordingly, R&D expenditures are uniformly seen as crucial factor within the group of technological push factors, as they are aimed at increasing a firm’s knowledge capital stock, i.e. firm-internal technological and knowledge capabilities (e.g. Horbach, 2008), and thus should theoretically be relevant for both environmental process and product innovations (Ziegler, 2015). However, empirical results are ambiguous.⁶ For example, Rehfeld et al. (2007) include a dummy variable indicating whether a firm conducted R&D and find a (weakly) significantly positive effect on environmental product innovations, but no significant effect on environmental process innovations. Horbach (2008) finds that firms being active in R&D activities

⁶ Please note that it is generally not trivial to compare empirical results across different studies, as they not only differ in terms of region or sectors, but also regarding dependent variables (i.e. measures for environmental innovations) or explanatory variables (e.g. measures for R&D). Hence, the following overview can only give an impression and we refer to several extant reviews for a more detailed overview (e.g. Bossle et al., 2016; Del Rio et al., 2016; Hojnik and Ruzzier, 2016). This also applies to all further variables that are discussed in the following.

are significantly more likely to improve or develop new environmental products. Kammerer (2009) uses the ratio of R&D employees to all employees as measure for R&D and finds no significant effect on environmental product innovations. Finally, Ziegler (2015) also finds that R&D activities, which have been carried out in the previous year, positively affect the probability to conduct environmental process and product innovations, and concludes that R&D is a key factor for the encouragement of environmental innovations. Also studies that use different kinds of measures for environmental innovations or R&D activities find rather positive (e.g. De Marchi, 2012; Ghisetti et al., 2015) or non-significant effects (e.g. Frondel et al., 2008; Horbach et al., 2012; Borghesi et al., 2015; Antonioli and Mazzanti, 2017).

Besides R&D expenses, a firm's knowledge capabilities required for environmental innovations could be increased by the employees' qualification and thus by employee training measures with the objective to make employees familiar with organizational changes (e.g. Antonioli et al., 2013, Horbach, 2008; Horbach et al., 2012). Indeed, Horbach (2008) finds a significant positive effect of the share of highly qualified employees on environmental product innovations, but no significant effect on environmental innovations in general. Antonioli and Mazzanti (2017) find a positive effect of the share of workers covered by training programs on the likelihood to conduct environmental innovations. However, Horbach et al. (2012) find that the qualification of the employees (measured by the share of employees with a university degree) has even a negative effect on the probability to conduct environmental innovations compared to other innovations and argue that environmental innovations rely less on human capital than other innovations. Similarly, Rennings et al. (2006) also find a significant negative effect of employment qualification on the probability to conduct environmental product innovations. Finally, Borghesi et al. (2015) find rather no significant impact of training programs in firms on the reduction of energy or CO₂.

Another important group of firm-internal factors can be summarized as organizational measures (e.g. Ziegler, 2015). Hereby, the implementation of environmental management systems (EMS) probably represents the most important measure. EMS are non-mandatory organizational frameworks (e.g. Rennings et al., 2006; Demirel and Kesidou, 2011), which require the voluntary action of a firm (e.g. Wagner, 2007), and are thus also understood as "unilateral agreements" (e.g. Ziegler, 2015) or self-regulation measures of firms (e.g. Frondel et al., 2008). They typically require the publication of an environmental policy, implementation of environmental programs, regular sustainability reports, or additional audits. Moreover, they can be certified by independent third parties, for example according to ISO 14001. According to the re-

source-based view of a firm (Wernerfelt, 1984), their introduction can, like the two factors before, increase the innovation capabilities within a firm, especially for the early stages in the innovation process (e.g. Ziegler, 2015), and thus support successful technological environmental innovations (e.g. Wagner, 2007; Ziegler, 2015). They particularly serve as learning and coordination process (e.g. Rennings et al., 2006; Wagner, 2008), which helps to overcome incomplete information about more efficient and cost-saving technologies (Horbach et al., 2012; Ziegler, 2015), new product opportunities (e.g. Horbach, 2008), and thereby foster the integration of environmental considerations into production processes (e.g. Frondel et al., 2008). Thus, although EMS are generally targeted to foster environmental process innovations, they may have an indirect impact on product innovations (e.g. Rennings et al., 2006) and thus also the firm's image (e.g. Frondel et al., 2008). However, Wagner (2007, 2008) argues that firms can behave opportunistically due to asymmetric information, and thus EMS could only be a symbolic gesture without any impact. Variables capturing whether a firm has introduced (certified or uncertified) EMS are considered in almost all empirical studies (Del Rio et al., 2016), and empirical evidence for both theoretical positions can be found. For example, Rennings et al. (2006) and Rehfeld et al. (2007) find a positive effect of EMS on both environmental process and product innovations. Rehfeld et al. (2007) conclude that certified companies see environmental issues as integral element of their company strategy. However, other studies only find a positive effect on environmental process innovations, and no or only occasionally a significant effect on environmental product innovations, depending on the model specification (e.g. Wagner, 2007, 2008; Horbach et al., 2012; Ziegler, 2015). Accordingly, Wagner (2007) concludes that EMS effects are limited to processes. Nevertheless, Horbach (2008) also finds a significant positive effect on environmental process innovations. Hence, results on environmental product innovations need further qualification (e.g. Wagner), particularly as other studies also find no significant effects of (certified) EMS (e.g. Frondel et al., 2008; Borghesi et al., 2015) suggesting that EMS are just symbolic and have no real impact on environmental innovations.

Accordingly, researchers agree that it is additionally important to consider other, more specific environmental organizational management measures, such as waste disposal measures, take-back or recycling measures, life-cycle assessment activities (e.g. Ziegler, 2015), or environmental labels, which are not necessarily covered by EMS. Rehfeld et al. (2007) argue that firms conducting these measures are interested in their products (even after the diffusion phase) and should be more likely to be environmental innovators. According to Wagner (2008), environmental labels could, similar to EMS, increase the knowledge capabilities. They may further signalize consumers that the firm considers environmental issues, as it develops environmental

friendly products in line with the standards of the label (e.g. Wagner, 2008).⁷ However, empirical results are mixed again. While Rehfeld et al. (2007) find significant positive effects of waste disposal and take-back systems on environmental product innovations, they find no significant effect of life-cycle assessment activities neither on environmental process nor product innovations. This is in line with results by Wagner (2008), who finds no significant effects for product recycling measures or life-cycle assessment activities. In contrast, Ziegler (2015) finds a positive effect of life-cycle assessment activities on both, but waste disposal measures are solely positively related to environmental product innovations. With respect to environmental labels, Wagner (2008) finds a significant positive effect of environmental labelling on environmental product, but not process innovations. Rehfeld et al. (2007) find no significant effect at all, which leads them to the conclusion that firms do not care about labels.

Finally, general organizational measures, such as a quality management system certified according to ISO 9001 may push a firm to more efficient production processes (e.g. Ziegler, 2015). While Horbach (2008) and Ziegler (2015) indeed find a positive effect of the introduction of new organizational measures on environmental innovation or positive relationship between an ISO 9001 certification and environmental process innovation, respectively, others find no significant effects of a quality management system neither on environmental process nor product innovations (e.g. Wagner, 2007; Rehfeld et al., 2007), which lead Rehfeld et al. (2007) to the conclusion that general measures are less important than EMS.

Besides technological push factors, other firm-specific factors, such as firm size or age might play a role. Generally, the effect of firm size is unclear from a theoretical perspective (e.g. Horbach, 2008; Ziegler, 2015) and empirical evidence is ambiguous. Larger firms could be more likely to introduce environmental innovations as they have a higher amount of financial and human resources (e.g. Kammerer, 2009) or advantages in handling complex environmental innovations (e.g. Del Rio et al., 2016), i.e. have large scale advantages (e.g. Ziegler, 2015). On the other hand, smaller firms could be more flexible (e.g. Ziegler, 2015). Empirically, this issue cannot be entirely resolved as some studies find positive effects of firm size on both environmental process and product innovations (e.g. Rehfeld et al., 2007; Triguero et al., 2013; Ziegler, 2015), other find only a positive effect on process innovations and no significant effects on product innovations (e.g. Rennings et al., 2006; Horbach et al., 2012), or no significant effects at all (e.g. Frondel et al., 2008; Wagner, 2008; Kammerer, 2009). Wagner (2007) even finds a weakly significant negative effect of firm size on environmental process innovations and no

⁷ For a detailed discussion of the role of labeling schemes, and mandatory or voluntary product standards in general, on environmental innovations see Roger (2018).

significant effect on environmental product innovations. Finally, some studies also consider a firm's age (e.g. Rehfeld et al., 2007), as it might be positively related to its internal capabilities. However, most studies only find a non-significant influence of age on environmental innovations (e.g. Del Río et al., 2016; Horbach, 2008).

Besides firm internal factors, external factors, such as market pull or demand side factors can theoretically influence environmental innovations. These factors comprise consumer preferences for environmentally friendly products, the firm's image, market structures or general pressure from (environmental conscious) consumers or competitors (e.g. Rennings, 2000; Horbach, 2008; Ziegler, 2015). Hence, they should be particularly important in the diffusion phase (Hojnik and Ruzzier, 2016) and for environmental product innovations (e.g. Rennings, 2000). Empirical evidence on the impact of market pull factors is mixed and the role of market pull factors has not been clarified yet, as even review studies report diverging results (e.g. Del Rio et al., 2016; Hojnik and Ruzzier, 2016). While some studies find that demand factors positively affect the firm's decision to conduct environmental innovations (e.g. Horbach et al., 2008; Kammerer, 2009; Kesidou and Demirel, 2012; Triguero et al., 2013), and thus find evidence for the demand pull hypothesis (e.g. Horbach, 2008), other studies find no hint for market pull factors stimulating environmental innovations (e.g. Rehfeld et al., 2007; Ziegler, 2015). In order to shed more light on this issue, our study aims to capture market pull factors by including four indicators that have been already included by previous studies, namely whether the firm is active on an environmental market, customer satisfaction, product quality, and whether the firm conducts corporate social responsibility (CSR) activities.

Regarding the first factor, Ziegler (2015) argues that it is important whether firms are active on environmental markets as these firms have a higher incentive to develop new environmental friendly products as important competition factors. Indeed, studies considering this issue find positive effects on environmental product innovations, but no significant effects for process innovations (e.g. Rennings et al. 2006; Wagner, 2008; Ziegler, 2015). Rehfeld et al. (2007) find that environmental product innovations, but not process innovations, are positively related to the firm's view that customer satisfaction is an important competitive factor on their most important sales market. Also, Kammerer (2009) finds that customer benefits are indeed a strong pull factor for product innovations. Nevertheless, other studies, find no significant effect of customer pressure on their measure for environmental innovation (e.g. Frondel et al., 2008). Similar, product quality should also be positively related to both product and process innovations (Ziegler, 2015). While Ziegler finds no significant of the importance of product quality, Horbach et al. (2013) find a positive effect on environmental innovations in Germany, but not

France, compared to general innovations. Another factor that may reflect the firm's strategy through signaling its commitment to green issues and building a green image are CSR activities (e.g. Demirel and Kesidou, 2011; Kesidou and Demirel, 2012). While Kesidou and Demirel (2012) indeed find a positive relationship of CSR activities to environmental innovations, Demirel and Kesidou (2011) find no significant effect on the amount of environmental R&D investments and only a weak significantly positive effect on investments into cleaner production technologies, leading them to doubt the effectiveness of voluntary agreements by firms.

Besides, these internal and external factors, regulatory push/pull factors can play an important role in the context of environmental innovations (e.g. Hojnik and Ruzzier, 2016), which shows the importance of policy measures to overcome the double externality problem (Horbach et al., 2012). However, our study has the same limitations as previous studies (e.g. Horbach, 2008; Ziegler, 2015) meaning that we cannot capture these factors with our dataset directly. Furthermore, Ziegler (2015) discusses several issues and problems concerning the consideration of regulation factors in the econometric analysis. Hence, our study exclusively focuses on the importance of market pull factors and technological push factors including organizational measures. Nevertheless, we assume that we can control for country-specific or sector-specific regulatory effects by the inclusion of sector and country fixed effects in the empirical analysis.

3. Data and variables

3.1 Data description

The panel data for our empirical analysis stem from Thomson Reuters Datastream, which contains the databases ASSET4 ESG and Worldscope Fundamentals. The ASSET4 ESG database comprises longitudinal data on environmental, social, and governance (ESG) issues of more than 7,000 globally located firms that are publicly listed in the MSCI World, MSCI Europe, STOXX 600, NASDAQ100, Russel 1000, FTSE250, ASX 300, or MSCI Emerging Markets. Hence, the firms are rather large. The database contains more than 750 single datapoints for the time period from 2002 to 2018, which are usually summarized into several indicators to assess the firms' sustainability performance at various levels (e.g. the environmental performance, social performance, or corporate governance performance). However, we are not interested in the aggregated indicators, but in some of the single datapoints, which serve as basis for our dependent variables as well as most of our explanatory variables, as described below. We additionally access Worldscope Fundamentals, which was founded in 1987 and contains financial data for more than 85,000 firms.

While the databases contain information from several economic sectors, and thus also for transport and service sectors, we only consider firms from manufacturing or production sectors. Indeed, service sectors has been largely neglected so far (e.g. Del Rio et al., 2016) and some studies also consider companies from service sectors, such as the financial sector (e.g. Horbach, 2008; Horbach et al., 2012) or specifically focus on service sectors (e.g. Cainelli and Mazzanti, 2013). However, we follow studies that only focus on firms from manufacturing sectors (e.g. Rehfeld et al., 2007; Frondel et al., 2008; Wagner, 2007, 2008; De Marchi, 2012; Antonioli et al., 2013; Antonioli and Mazzanti, 2017) as the consideration of service sectors should blur our results due to increased heterogeneity. Further, we believe that environmental process or product innovations of manufacturing and service firms should be very different and thus not directly comparable.⁸ Hence, we categorized the firms according to the Industry Classification Benchmark (ICB)⁹ and excluded all firms from the (sub-) sectors “Industrial Transportation (2770)”, “Support Services (2790)”, “Health Care Providers (4533)”, “Consumer Services (5000)”, “Telecommunications (6000)”, “Financials (8000)”, and “Software & Computer Services (9530)”.

3.2 Description of variables

3.2.1 Dependent variables

As discussed above, it is important to distinguish between environmental process and product innovations, as their determinants could be different due to the different underlying objectives (e.g. Rehfeld et al., 2007; Wagner, 2008; Horbach et al., 2012; Triguero et al., 2013; Ziegler, 2015). Accordingly, we construct two dependent variables with the aim to capture environmental process and product innovations separately.

We use the ASSET4 datapoint “New production techniques” to capture whether a firm has introduced environmental process innovations during a year. The exact formulation of the related question is “Does the company report on new production techniques to improve the global environmental impact (all emissions) during the production process?”. On this basis, we construct the binary variable “environmental process innovations” that takes the value one if the company has reported on new production techniques improving the environmental impact during the production process, and zero otherwise. An overview for this and all following variables and the exact formulations of the corresponding questions are presented in Table 1.

⁸ Descriptive statistics also highlight that only very few firms from transport or service sectors have conducted environmental process or product innovations.

⁹ See <https://www.ftserussell.com/financial-data/industry-classification-benchmark-icb> (assessed on January 29, 2019).

In order to capture environmental product innovations, we use the ASSET4 datapoint “Environmental R&D”, which refers to the question “Does the company invest in R&D on new environmentally friendly products or services that will limit the amount of emissions and resources needed during product use?”. The corresponding binary variable “environmental product innovations” takes the value one if the question was answered with yes, and zero otherwise. In contrast to the first dependent variable, this question has obviously several weaknesses, particularly as it does not capture an outcome, but is rather one of several input factors at the beginning of the innovation process (e.g. Kleinknecht et al., 2002; Ziegler, 2015). Unfortunately, as also discussed by Reif and Rexhäuser (2018), this is the only adequate datapoint in the ASSET4 database, which we can use. An alternative datapoint, namely “environmental R&D investment costs” has too many missing values. However, we are confident that we still have a good proxy for environmental product innovations, as several studies use similar measures for (environmental) innovations (e.g. Demirel and Kesidou, 2011; Kesidou and Demirel, 2012).

3.2.2 Explanatory variables

We construct several explanatory variables to capture different technological push factors. In contrast to other studies, which just have qualitative information on the corporate R&D activities (and thus can only include dummy variables to capture R&D activities, e.g. Horbach et al., 2012; Ziegler, 2015), we have information on the firm-internal R&D expenditures, and can thus construct a continuous variable “log R&D expenses” indicating the logarithmized R&D expenses plus one. We add the value one to all R&D expenditures before taking the logarithm in order to circumvent the exclusion of firms with zero R&D expenses (e.g. Wooldridge, 2009).¹⁰ In order to consider how internal job trainings for employees can contribute to increase internal knowledge capabilities and thus environmental innovations, we construct the dummy variable “employee training” that takes the value one if the firm trains its employees on environmental issues, and zero otherwise. On the basis of the ASSET4 datapoint “ISO 14000 or EMS”, which refers to the question “Does the company claim to have a certified Environmental Management System?”, we construct the dummy variable “EMS” that takes the value one if the company has any certified environmental management system at all, and zero otherwise (e.g. Horbach et al.,

¹⁰ For robustness checks, we also considered a dummy variable that takes the value one if a firm’s R&D expenditures are greater than zero. However, the mean across all firms for the period between 2004 to 2017 is 0.98, which indicates that almost all firms in the sample invest in R&D and there is only little variation in this variable, which would be problematic for the empirical analysis. This also means that we would lose about 2% of the observations, if we would not add the value one to all R&D expenditures before taking the logarithm.

2012; Ziegler, 2015). As the certification of EMS could only be a symbolic gesture (e.g. Wagner, 2008), we construct four further variables in order to capture environmental organizational measures. The dummy variable “waste reduction measures” takes the value one if the firm reports on initiatives to recycle, reduce, reuse, substitute, treat or phase out any type of waste, and zero otherwise. Similarly, the dummy variable “take-back and recycling” takes the value one if the firm reports about take-back procedures and recycling programs to reduce the potential risks of products entering the environment, and zero otherwise. Finally, the dummy variables “life-cycle assessment” and “environmental label” take the value one if the firm has a product life-cycle assessment policy or uses product labels that indicate the environmental responsibility of its products, respectively.

In line with previous studies (e.g. Ziegler, 2015), we also include an indicator for general organizational measures. Therefore, we construct the dummy variable “ISO 9000” that takes the value one if the firm claims to have an ISO 9000 certification or any industry specific certification, and zero otherwise. As final internal firm-specific factors, we control for firm size by including the variable “log employees” that captures the logarithmized number of employees within a firm.

We use four different firm-specific indicators to capture market pull factors. The dummy variable “environmental market” (e.g. Horbach, 2008; Ziegler, 2015) takes the value one if a firm reports on at least one product line or service that is designed to have positive effect on the environment or which is environmentally labeled and marketed, and zero otherwise. The dummy variable “customer satisfaction strategy” refers to two datapoints in the ASSET4 database, and takes the value one if the firm either has a policy to improve customer satisfaction or describes, claims to have or mentions processes in place to improve customer satisfaction, respectively, and zero otherwise. The dummy variable “product quality policy” takes the value one if the firm has a quality policy for products and services, and zero otherwise. Finally, the dummy variable “CSR strategy” takes the value one if the firm has a CSR committee or team, and zero otherwise. Additionally, we construct dummy variables for the different countries and sectors (at the ICB industry level).

4. Econometric analysis

4.1 Descriptive statistics

Table 2 reports the absolute and relative frequencies of environmental process and product innovations from 2002 to 2018. It reveals that the panel is unbalanced and the number of annual

total observations increases over time. The lowest number of observations falls into the years 2002 (with 213 observations), 2003 (215), and 2018 (43), while over 500 observations exist for the years from 2015 to 2017. Accordingly, we exclude the observations from the years 2002, 2003, and 2018 from the subsequent analysis. Further, Table 2 also reveals a clear positive time trend for the frequencies of both kinds of innovations. That is, while only 6% of the firms conducted environmental process innovations in 2004, 28% conducted this kind of innovation in 2017. For environmental product innovations, the shares range from 9% to 39% for the same time period. The maximum values can be observed during the year 2013 for both kinds of innovations, while the relative frequency of environmental product innovations is always larger than the share of environmental process innovations.¹¹

Table 3 reports descriptive statistics for all dependent and explanatory variables for the time period from 2004 to 2017. It reveals that the sample contains observations for the two dependent variables (i.e. “environmental process innovations” and “environmental product innovations”) for 651 European firms, which are part of the sample for about 9.6 years on average. As already discussed before, the overall mean of environmental process innovations is lower than the overall mean for environmental product innovations (i.e. 0.252 versus 0.351). Additionally, we see that on average 73.4% of the firms have certified EMS and 53.4% are certified according to ISO 9000. The overall means for the remaining organizational measures are also lower than the means for “EMS”, namely 0.659 for “waste reduction measures”, 0.146 for “take-back and recycling”, 0.369 for “life-cycle assessment”, and only 0.085 for “environmental label”. The overall means for market pull factors are rather high. On average, 42.7% of the firms are active on an environmental market, 79.5% have a customer satisfaction strategy, 81.5% have introduced a product quality policy, 60.1% conduct environmental employee training programs, and 54.3% have implemented a CSR strategy. Finally, we see that the number of observations for the variable “log R&D expenses” is with 480 observations slightly lower compared to the other variables.

The summary statistics for the different industry sectors and the countries for the time period from 2004 to 2017 are reported in Table 4 and 5. Table 4 shows that the majority of the firms in the sample belongs to the sector “Industrials” (on average 25.7%), followed by firms from the sector “Consumer goods” (20.6%). Only 4.4% and 8.1% of the firms are from the sectors “Technology” and “Utilities”, respectively. The largest number of firms stem from the

¹¹ These numbers differ from previous studies, such as Rehfeld et al. (2007) or Ziegler (2015), which observe more environmental process than product innovations.

United Kingdom (UK), with a share of 28.3% on average, followed by Germany (10.2%), France (8.7%), Switzerland (7.6%), Sweden (6.4%), Italy (4.7%), and Spain (4.6%).

4.2 Estimation results

Due to the binary nature of our dependent variables, we apply binary logit models. In order to account for unobserved heterogeneity, we not only consider Maximum Likelihoods (ML) estimates of the parameters in traditional (pooled) binary logit models, but also conduct random effects and fixed effect estimations. Further, though we consider very simple model specifications at this preliminary stage of our study, we already consider not only contemporaneous explanatory variables, but also one model specifications with lagged explanatory variables (e.g. Demirel and Kesidou, 2011).

The ML estimation results on the basis of all three estimations approaches and both model specifications for the determinants of environmental process and product innovations are reported in Table 6 and Table 7, respectively. Two general issues become obvious directly. First, we lose a huge number of observations in the fixed effects estimation approach due to the fact that a severe number of the observations for the dependent variables are time-invariant, i.e. always take the value one or zero, respectively. Secondly, we see that the results qualitatively differ across the three estimation approaches. This means, for example, that some parameters are significantly different from zero in the pooled logit models, but not in the random effects (or fixed effects) models, and vice versa. Hence, unobserved heterogeneity seems to be an issue and it is strongly confirmed in the corresponding likelihood ratio tests in the case of random effects estimations. As a consequence, we assume that the results of the pooled logit model and the fixed effects model have to be interpreted with caution and we focus on the random effects estimation results in the following.

Regarding environmental process innovations, we find no significant effect of contemporaneous logarithmized R&D expenses, but a weakly significantly positive relation to lagged variables (even highly significantly for the fixed effects estimation). However, other measures that may increase knowledge capabilities seem to be more important, as environmental employee trainings significantly positively affect the probability to conduct environmental innovations in both model specifications. Interestingly, we find that certified EMS have no significant effect in any of the model specifications. This supports Wagner (2007, 2008) who argues that EMS might only work through their implementation and not their certification, which might be just a reaction to pressure from relevant stakeholders (e.g. Kammerer, 2009). Similarly, Frondel et al. (2008) also find no empirical evidence that EMS stimulate environmental inno-

vations and argue that the absence of sanctions or the firms' desire to disguise their poor environmental performance could be reasons for their results. Indeed, it seems as if other specific, implemented environmental management measures are more important. For all further contemporaneous explanatory variables of environmental organizational measures, namely "waste reduction measures", "take-back and recycling", "life-cycle assessment", and "environmental label", we find a (at least weakly) significantly positive effect on the probability to conduct environmental process innovations. For "life-cycle assessment" and "environmental label", we additionally find significant lagged effects. The remaining two included technology push factors, namely "ISO 9000" and "log employees", only seem to play a minor role, as we only find a weakly significant positive effect of the lagged logarithmized number of employees. Though, this variable has a significant effect in the pooled binary logit model, which not only shows that unobserved heterogeneity is present, but that the results can be very misleading if no appropriate econometric approaches are applied. Finally, we find almost no significant effect of any market pull factor on environmental process innovations. Only the presence of a customer satisfaction strategy and lagged "CSR committee" are weakly significantly and positively related to environmental process innovations. Hence, these results are totally in line with the findings by Ziegler (2015), who also finds no evidence for the demand pull hypothesis in the case of environmental process innovations.

Table 7 shows that R&D expenses seem to more important for environmental product than for process innovations, as we find highly significant and positive effects for the contemporaneous as well as lagged variables in the random effects model. The presence of environmental employee trainings also positively affects the introduction of environmental product innovations. Interestingly, we also find positive effects for both "EMS" variables, although these management systems are rather designed to foster process innovations (e.g. Rennings et al., 2006). Nevertheless, we also find weak evidence that other organizational measures play a role, such as take-back and recycling measures, but especially life-cycle assessment activities and environmental labels. Hence, in line with Rehfeld et al. (2007), firms that are more interested in the products' environmental impact over their life-cycle and whether their compliance with certain standards are more likely to introduce environmental product innovations. However, waste reduction measures seem to rather affect environmental process innovations and not environmental product innovations. Thus, the finding by Rehfeld et al. (2007) that waste disposal measures are more important than EMS cannot be supported by our own results. Finally, regarding firm-internal factors, we find that (contemporaneous) firm size and "ISO 9000" are (weakly) significantly positively related to environmental product innovations. Also, market pull factors play

a more important role than in the case of environmental process innovations. That is, firms being active on an environmental market or having implemented a customer satisfaction strategy or product quality policy, are more likely to conduct environmental product innovations. We also find a significant positive effect of having a CSR committee in the previous period.

5. Conclusions, discussion and outlook

Policymakers and researchers agree that technological environmental innovations can play an important role for achieving (inter-) national climate policy goals and sustainable development, as they can significantly contribute to the reduction of firms' negative environmental externalities. However, environmental innovations are prone to the "double externality" problem and thus require additional, specific policy measure, i.e. beyond normal measures to promote innovations activities (e.g. Rennings, 2000). Accordingly, a main path in this research field aims to empirically identify the determinants of these innovations, in order derive appropriate policy implications. However, empirical studies mostly focus on a single country and/or a single point in time, and no study has considered a broad panel dataset over a long time period at the firm level yet. Hence, so far it was merely not possible to control for unobserved heterogeneity or to consider the dynamics of environmental innovations. The aim of our paper is to close these research gaps.

Hence, in contrast to previous studies, this paper empirically examines the determinants of corporate environmental product and process innovations on the basis of panel data for firms from 25 European countries between 2004 and 2017 from the ASSET4 and Worldscope databases. This allows us to control for unobserved heterogeneity and time effects. Our fixed and random effects estimations in binary logit models reveal the relevance of this flexible panel data analysis. The estimation results imply positive effects especially of environmental training programs for employees and implemented environmental organizational measures, such as waste disposal systems, or life-cycle assessment or environmental labels, on environmental process innovations. Interestingly, certified environmental management systems (EMS), certified quality management systems, and market pull factors seem to play no role for environmental process innovations. This supports findings by previous studies that also find no significant effects of EMS (e.g. Wagner, 2007, 2008; Frondel et al., 2008) or market pull factors (e.g. Ziegler, 2015). However, our results show that these factors are rather relevant for environmental product innovations, which are also additionally affected by several technological push factors. This means that certified (environmental or quality) management systems are important,

although they do not seem to directly affect environmental process innovations. This also underlines the findings of previous studies showing that environmental process and product innovations are driven by different factors. Hence, it is important to distinguish between these two innovation types in empirical analyses. Further, our results suggest that soft policy instruments to foster voluntary management measures or the adoption of labeling schemes (e.g. Rehfeld et al., 2007) seem to be still appropriate. However, in order to additionally strengthen environmental process innovations, it is necessary to focus on the implementation of specific measures instead of their pure certification.

At this stage, our empirical analysis still has some flaws, which we will address in the next steps. First and foremost, we have to more deeply analyze the quality of the second dependent variable, i.e. “environmental product innovations”, which is rather an input factor (although it has been used in previous studies, as discussed above). Secondly, we will consider a variety of robustness checks with respect to different variable specifications, sub-samples, and particularly model specifications. This especially means that we will consider different model specifications with contemporaneous and lagged explanatory, but also dependent variables. This would enable us to analyze path dependencies, i.e., for example, whether innovations breed innovations (e.g. Horbach, 2008; Ziegler, 2015). However, this would require appropriate panel estimation approaches, such as approaches according to Arellano and Bond (1991) or Arellano and Bover (1995), which cannot be easily conducted in non-linear models, such as binary logit models. Hence, we probably have to apply analyses on the basis of linear regression models. These exercise will hopefully help us to contribute to the discussion on endogeneity and (reverse) causality issues in this research field (e.g. Wagner, 2007, 2008; Ziegler and Nogareda, 2009). Finally, we will also provide an in-depth analysis in order to reveal potential differences across countries. Thereby, we will particularly focus on the countries with the largest number of observations, i.e. the UK, Germany, France, Switzerland, Sweden, Italy, and Spain.

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Tables

Table 1: Overview of all variables, their data sources, and exact descriptions

Variable(s)	Datapoint(s)	Code(s)	Description(s) / question(s)
Variables from ASSET4 database			
Environmental process innovation	New production techniques	ENERDP069	Does the company report on new production techniques to improve the global environmental impact (all emissions) during the production process?
Environmental product innovation	Environmental R&D	ENPIDP024	Does the company invest in R&D on new environmentally friendly products or services that will limit the amount of emissions and resources needed during product use?
Employee training	Environment Management Training	ENRRDP008	Does the company train its employees on environmental issues?
EMS	ISO 14000 or EMS	ENERDP073	Does the company claim to have a certified Environmental Management System?
Waste reduction measures	Waste Reduction Initiatives	ENERDP062	Does the company report on initiatives to recycle, reduce, reuse, substitute, treat or phase out any type of waste?
Take-back and recycling	Take-back and Recycling Initiatives	ENPIDP047	Does the company reports about take-back procedures and recycling programs to reduce the potential risks of products entering the environment?
Life-cycle assessment	Product Innovation Policy Elements/Life Cycle Assessments	ENPIDP0011	Does the company have a product life-cycle assessment policy?
Environmental label	Env Labels	ENPIDP062	Does the company use product labels (e.g., FSC, Energy Star, MSC) indicating the environmental responsibility of its products?
ISO 9000	ISO 9000	SOPRDP021	Does the company claim to have an ISO 9000 certification or any industry specific certification (QS-9000-automotive, TL 9000-telecommunications, AS9100-aerospace, ISO/TS 16949-automotive, etc.)?
Environmental market	Environmental products	ENPIDP019	Does the company report on at least one product line or service that is designed to have positive effect on the environment or which is environmentally labeled and marketed?
Customer satisfaction strategy	Client Loyalty Policy Elements/Customer Satisfaction Client Loyalty Processes/Customer Satisfaction	ECCLDP0011 ECCLDP0081	Does the company have a policy to improve customer satisfaction? Does the company describe, claim to have or mention processes in place to improve customer satisfaction?
Product quality policy	Product Responsibility Policy/Quality	SOPRDP0012	Does the company have a products and services quality policy?

CSR strategy	CSR Sustainability Committee	CGVSDP005	Does the company have a CSR committee or team?
Variables from Worldscope database			
Log R&D expenses	Research & Development (WS) (Key item)	WC01201	RESEARCH AND DEVELOPMENT EXPENSE represents all direct and indirect costs related to the creation and development of new processes, techniques, applications and products with commercial possibilities.
Log employees	Employees	WC07011	EMPLOYEES represent the number of both full and part time employees of the company.

Table 2: Absolute and relative frequencies of environmental process and product innovations by European firms across time

Year	Environmental process innovations			Environmental product innovations		
	Absolute frequency	Relative frequency	Total number of observations	Absolute frequency	Relative frequency	Total number of observations
2002	14	0.07	213	25	0.11	213
2003	8	0.04	215	23	0.11	215
2004	19	0.06	327	31	0.09	327
2005	34	0.09	384	45	0.12	384
2006	37	0.09	391	55	0.1	391
2007	65	0.16	404	92	0.23	404
2008	100	0.24	421	138	0.33	421
2009	113	0.26	436	167	0.38	436
2010	130	0.28	460	192	0.42	460
2011	145	0.31	470	203	0.43	470
2012	159	0.34	471	213	0.45	471
2013	160	0.34	474	218	0.46	474
2014	159	0.33	479	217	0.45	479
2015	156	0.31	507	212	0.42	507
2016	155	0.30	512	207	0.40	512
2017	140	0.28	502	197	0.39	502
2018	12	0.28	43	11	0.25	43

Table 3: Descriptive statistics for dependent and explanatory variables (time period: 2004-2017)

Variable	Total number of observations	Number of firms	Average number of years a firm was observed	Mean	Median	Standard deviation	Min	Max
Environmental process innovations	6238	651	9.582	0.252	0	0.434	0	1
Environmental product innovations	6238	651	9.582	0.351	0	0.477	0	1
Log R&D expenses	5163	480	10.756	10.893	11.112	2.686	0	17.592
EMS	6238	651	9.582	0.734	1	0.442	0	1
Waste reduction measures	6238	651	9.582	0.659	1	0.474	0	1
Take-back and recycling	6238	651	9.582	0.146	0	0.353	0	1
Life-cycle assessment	6238	651	9.582	0.396	0	0.489	0	1
Environmental label	6238	651	9.582	0.085	0	0.278	0	1
ISO 9000	6229	650	9.583	0.534	1	0.499	0	1
Log employees	7631	652	11.704	8.902	9.029	1.861	0	13.373
Environmental market	6238	651	9.582	0.427	0	0.495	0	1
Customer satisfaction strategy	6234	647	9.635	0.795	1	0.404	0	1
Product quality policy	6229	650	9.583	0.815	1	0.388	0	1
Employee training	6238	651	9.582	0.601	1	0.490	0	1
CSR strategy	5816	650	8.948	0.543	1	0.498	0	1

Table 4: Descriptive statistics for sector dummies (time period: 2004-2017)

ICB code	Industry	Mean	Standard deviation	Min	Max
0001	Oil & gas	0.124	0.329	0	1
1000	Basic materials	0.156	0.363	0	1
2000	Industrials	0.257	0.437	0	1
3000	Consumer goods	0.206	0.405	0	1
4000	Health care	0.131	0.338	0	1
7000	Utilities	0.081	0.273	0	1
9000	Technology	0.044	0.206	0	1

Table 5: Descriptive statistics for country dummies (time period: 2004-2017)

Country	Mean	Standard deviation	Min	Max
Austria	0.015	0.123	0	1
Belgium	0.020	0.140	0	1
Cyprus	0.003	0.055	0	1
Czech Republic	0.002	0.039	0	1
Denmark	0.028	0.164	0	1
Finland	0.032	0.176	0	1
France	0.087	0.282	0	1
Germany	0.102	0.303	0	1
Greece	0.020	0.140	0	1
Guernsey	0.002	0.039	0	1
Hungary	0.003	0.055	0	1
Ireland	0.038	0.192	0	1
Isle of Man	0.002	0.039	0	1
Italy	0.047	0.213	0	1
Jersey	0.008	0.087	0	1
Luxembourg	0.006	0.078	0	1
Netherlands	0.060	0.237	0	1
Norway	0.026	0.159	0	1
Poland	0.023	0.150	0	1
Portugal	0.006	0.078	0	1
Spain	0.046	0.209	0	1
Sweden	0.064	0.245	0	1
Switzerland	0.076	0.266	0	1
Ukraine	0.002	0.039	0	1
United Kingdom	0.283	0.450	0	1

Table 6: Estimated parameters (cluster robust standard errors) in binary logit models with contemporaneous and lagged explanatory variables (dep. variable: Environ. process innovations)

Variable	Pooled	Pooled	RE	RE	FE	FE
Log R&D expenses	0.070 (0.062)	-	0.217 (0.199)	-	0.224 (0.175)	-
Log R&D expenses (lagged)	-	0.079 (0.063)	-	0.467* (0.271)	-	0.527*** (0.186)
Employee training	0.591*** (0.229)	-	1.322** (0.526)	-	1.118*** (0.401)	-
Employee training (lagged)	-	0.577** (0.225)	-	1.101** (0.537)	-	0.745 (0.476)
Ems	-0.089 (0.356)	-	0.998 (0.967)	-	0.811 (0.607)	-
Ems (lagged)	-	-0.090 (0.344)	-	0.180 (0.931)	-	0.016 (0.738)
Waste reduction measures	0.961*** (0.257)	-	1.144*** (0.434)	-	0.757** (0.376)	-
Waste reduction measures (lagged)	-	0.759*** (0.234)	-	0.362 (0.526)	-	0.060 (0.457)
Take-back and recycling	-0.101 (0.280)	-	1.275* (0.710)	-	1.383** (0.648)	-
Take-back and recycling (lagged)	-	-0.098 (0.284)	-	0.843 (0.687)	-	0.976 (0.856)
Life-cycle assessment	0.682** (0.270)	-	1.456* (0.816)	-	0.285 (0.515)	-
Life-cycle assessment (lagged)	-	0.645** (0.260)	-	2.141** (1.017)	-	1.471 (0.896)
Environmental label	0.157 (0.350)	-	1.750* (1.007)	-	2.691** (1.240)	-
Environmental label (lagged)	-	0.192 (0.355)	-	2.571* (1.549)	-	2.791* (1.628)
ISO 9000	0.417* (0.224)	-	-0.483 (0.683)	-	-0.547 (0.397)	-
ISO 9000 (lagged)	-	0.464** (0.227)	-	-0.063 (0.646)	-	-0.332 (0.515)
Log employees	0.257** (0.114)	-	0.501 (0.683)	-	-0.131 (0.283)	-
Log employees (lagged)	-	0.264** (0.115)	-	0.880* (0.499)	-	0.267 (0.555)
Environmental market	0.057 (0.262)	-	0.696 (0.661)	-	0.620 (0.447)	-
Environmental market (lagged)	-	0.065 (0.253)	-	0.507 (0.616)	-	0.267 (0.573)
Customer satisfaction strategy	0.446 (0.363)	-	1.406* (0.783)	-	0.899 (0.712)	-
Customer satisfaction strategy (lagged)	-	0.279 (0.337)	-	1.388 (1.251)	-	1.086 (0.861)
Product quality policy	-0.222 (0.362)	-	0.974 (0.850)	-	0.753 (0.671)	-
Product quality policy (lagged)	-	-0.464 (0.330)	-	-1.259 (1.190)	-	-1.152 (0.787)
CSR committee	0.288 (0.224)	-	0.306 (0.444)	-	0.181 (0.394)	-
CSR committee (lagged)	-	0.367* (0.222)	-	0.493 (0.507)	-	0.369 (0.479)
Constant	-4.938*** (1.596)	-3.687** (1.503)	-15.551 (15.243)	-17.601** (7.567)	-	-
Sector dummies	Yes	Yes	Yes	Yes	-	-
Country dummies	Yes	Yes	Yes	Yes	-	-
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of total observations / firms	3628 / 442	3253 / 413	3628 / 442	3253 / 413	1219 / 106	935 / 86

Notes: * (**, ***) means that the appropriate effect is different from zero at the 10% (5%, 1%) significance level, respectively. Please note that only normal standard errors can be considered for the fixed effects estimations.

Table 7: Estimated parameters (cluster robust standard errors) in binary logit models with contemporaneous and lagged explanatory variables (dep. variable: Environ. product innovations)

Variable	Pooled	Pooled	RE	RE	FE	FE
Log R&D expenses	0.339*** (0.073)	-	0.509*** (0.144)	-	0.025 (0.188)	-
Log R&D expenses (lagged)	-	0.334*** (0.080)	-	0.473*** (0.174)	-	-0.557 (0.406)
Employee training	0.477** (0.218)	-	1.044** (0.411)	-	0.715** (0.345)	-
Employee training (lagged)	-	0.336 (0.226)	-	0.823* (0.457)	-	0.449 (0.406)
Ems	0.477* (0.273)	-	1.143** (0.553)	-	1.281** (0.579)	-
Ems (lagged)	-	0.478* (0.268)	-	1.192* (0.684)	-	1.367** (0.684)
Waste reduction measures	0.225 (0.230)	-	0.539 (0.433)	-	0.503 (0.341)	-
Waste reduction measures (lagged)	-	0.226 (0.236)	-	0.297 (0.483)	-	0.053 (0.393)
Take-back and recycling	0.362 (0.284)	-	0.810* (0.487)	-	0.591 (0.454)	-
Take-back and recycling (lagged)	-	0.491 (0.303)	-	1.801*** (0.492)	-	1.800*** (0.619)
Life-cycle assessment	0.716*** (0.249)	-	1.106** (0.480)	-	-0.011 (0.413)	-
Life-cycle assessment (lagged)	-	0.655** (0.254)	-	1.771*** (0.675)	-	0.785 (0.482)
Environmental label	0.116 (0.409)	-	1.894** (0.753)	-	2.019** (0.939)	-
Environmental label (lagged)	-	0.070 (0.423)	-	1.814** (0.839)	-	2.212** (1.105)
Log employees	0.055 (0.117)	-	0.448* (0.245)	-	0.110 (0.247)	-
Log employees (lagged)	-	0.043 (0.119)	-	0.328 (0.311)	-	-0.029 (0.273)
ISO 9000	0.587*** (0.203)	-	1.142** (0.504)	-	1.167*** (0.363)	-
ISO 9000 (lagged)	-	0.482** (0.205)	-	0.432 (0.491)	-	0.254 (0.389)
Environmental market	0.917*** (0.232)	-	0.739* (0.392)	-	0.088 (0.383)	-
Environmental market (lagged)	-	0.888*** (0.237)	-	0.499 (0.392)	-	-0.317 (0.422)
Customer satisfaction strategy	0.394 (0.399)	-	1.400* (0.809)	-	0.182 (0.658)	-
Customer satisfaction strategy (lagged)	-	0.361 (0.360)	-	1.338 (0.944)	-	-0.189 (0.628)
Product quality policy	0.782** (0.397)	-	1.403* (0.745)	-	0.732 (0.523)	-
Product quality policy (lagged)	-	0.724** (0.314)	-	1.478** (0.633)	-	0.872 (0.622)
CSR committee	0.408** (0.193)	-	0.599 (0.424)	-	0.398 (0.350)	-
CSR committee (lagged)	-	0.437** (0.198)	-	1.000** (0.484)	-	0.929** (0.441)
Constant	-6.355*** (1.396)	-5.762*** (1.378)	-16.584*** (3.386)	-14.176*** (4.051)	-	-
Sector dummies	Yes	Yes	Yes	Yes	-	-
Country dummies	Yes	Yes	Yes	Yes	-	-
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of total observations / firms	3639 / 444	3264 / 415	3639 / 444	3264 / 415	1768 / 158	1365 / 128

Notes: * (**, ***) means that the appropriate effect is different from zero at the 10% (5%, 1%) significance level, respectively. Please note that only normal standard errors can be considered for the fixed effects estimations.