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Eco-Innovation: Drivers, Barriers and Effects – A European Perspective

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Abstract

This paper determines the key drivers, barriers and effects of eco-innovation, in comparison to innovation in general. It further distinguishes between different types of eco-innovations to better capture their heterogeneous nature. It uses two different data sets: (1) the Community Innovation Survey 2014 (CIS-2014) for a large sample of EU Member States, further split up into three groups in accordance with their eco-innovation performance; (2) the German Mannheim Innovation Panel to address additional drivers the CIS-2014 is unable to capture. Results show that both R&D investments and complementary fixed capital investments are key drivers of eco-innovation, with differences across country groups. Results from the German sample further emphasise that expected future demand, rising costs for energy and other resources and the wish to improve one's reputation and the need to meet industry standards help spur eco-innovation, while public policy is only of limited importance. In contrast, international market orientation turns out to be a barrier for eco-innovation. By and large, eco-innovations also have a productivity-enhancing effect which is however lower as compared to innovations in general.

Keywords: eco-innovation, demand pull, technology push, public policy, Europe

JEL classification: Q55, O33, O38

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1. Introduction

Innovations are key to economic outcomes, both as an engine of economic growth and the development of economies and as a prerequisite for the survival and growth of firms (Schumpeter, 1934). In view of this, innovation – and with it environmental innovation – has been moved into the centre of the Europe 2020 strategy for smart, sustainable and inclusive growth and job creation. The European Commission defines eco-innovation as *'… any form of innovation resulting in or aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment, enhancing resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources*' (2011: 2).

In the context of the Europe 2020 strategy, eco-innovation is considered to play an important role due to two key advantages it generates: on the one hand, eco-innovation can address the EU's current key societal challenges by tackling climate change, helping to improve environmental protection and resource efficiency of the economy or to guarantee secure, clean and efficient energy. On the other hand, eco-innovation can contribute strongly to the EU's competitiveness and growth which have suffered from the recent global economic and financial crisis. Hence, to fully embrace and harness its full potential, the uptake of eco-innovation needs to be fostered and facilitated and still existing barriers need to be dismantled and effective policies implemented to promote, accelerate and diffuse eco-innovation in the EU.

This paper addresses these issues and sheds light on the key drivers of and barriers for eco-innovations and determines their effects on competitiveness. It uses firm-level data from the latest wave of the Community Innovation Survey (CIS-2014), pertaining to the period 2012-2014, from two different data sources: (i) Eurostat's microdata save centre for several EU Member States and (ii) the Mannheim Innovation Panel (MIP-2014) for German firms from the Centre of European Economic Research (ZEW). The broad EU sample is further split up into three sub-samples, in accordance with the relative eco-innovation performance of EU Member States as determined by the Eco-Innovation Scoreboard: (i) eco-innovation leaders, (ii) average eco-innovation performers, and (iii) countries catching-up in eco-innovation. This split allows to highlight differences across country groups as concerns drivers, barriers and effects of eco-innovation and to show what sets firms located in countries leading on eco-innovation apart from those located in countries which lag behind on eco-innovation. The MIP-2014, on the other hand, allows to shed light on additional aspects the standardised CIS is unable to address, such as particular motives for eco-innovation, most importantly in terms of the role of demand and public policies. The analysis looks at both, innovation in general as well as eco-innovation, in particular, which helps to identify important differences between innovation and eco-innovation. Eco-innovations are further distinguished in terms of different process and product eco-innovations which helps draw a more differentiated picture of the particular drivers, barriers and effects of each individual eco-innovation. Methodologically, a standard three-step CDM-model is used for this purpose.

Results show that investments either in the form of investments in R&D or of investments in machinery, equipment, software and buildings are key drivers of eco-innovations. However, these forms of investments are of different importance in the three country groups. For instance, the relative weak effect of R&D investments in countries catching-up in eco-innovation is reflective of the inefficiencies in the eco-innovation production process and insufficient innovation capabilities of firms located there. Furthermore, the strong effect of fixed capital investments (machinery, equipment, software and buildings) in countries with average eco-innovation performance and countries catching-up in eco-innovation points to the need to expand and upgrade the prevailing and probably still insufficient physical infrastructure to spur eco-innovation. Furthermore, the analysis of the German sample stresses the importance of expected future demand and rising costs for energy and other resources as incentives for eco-innovation but only finds a limited role for public policy. In particular, while public financial support encourages eco-innovations, little support is found for the Porter hypothesis which attributes a strong role to regulations to simulate eco-innovations (Porter and van der Linde, 1995). However, a further differentiation of eco-innovations into different process and product eco-innovations shows that regulations do matter, but only for some particular types of eco-innovations. This suggests that regulations are not a one-size-fits-all type of policy tool. Contrary to expectations, international market orientation is a barrier for eco-innovations, irrespective of country group or type of eco-innovation considered. Finally, rather consistently, eco-innovations are commercially beneficial – in terms of a productivity-enhancing effect – which is however lower than for innovations in general.

The rest of the paper is structured as follows: Section 2 gives an overview of the literature as concerns key drivers and barriers as well as effects of eco-innovations. Section 3 discusses the underlying methodological framework. The different data sets used in the analysis are described in section 4. Section 5 discusses the results of the econometric analysis. Finally, section 6 summarises and concludes.

2. Related literature

2.1. DETERMINANTS OF ECO-INNOVATION

Following Horbach et al. (2012), the key determinants of eco-innovation, as suggested by related empirical evidence, have been grouped into four groups: demand pull factors (see section 2.1.1), technology push factors (see section 2.1.2), public policy (see section 2.1.3), and firm characteristics (see section 2.1.4).

2.1.1. Demand pull factors

Although a number of different indicators have been used, empirical evidence rather consistently highlights that demand is an essential driver of eco-innovations. For instance, Horbach (2008) points to the importance of expectations and shows for a set of German manufacturing firms that strong (expected) demand helps trigger environmental innovations. The importance of demand expectations is also highlighted by the Flash Eurobarometer (2011) for which around 5,000 managers of SMEs in 27 EU Member States in selected sectors were interviewed in 2011. It shows that almost 70% of the interviewed managers considered uncertain demand from the market as very serious or somewhat serious problem for the development and uptake of eco-innovations.

Moreover, customer benefits of eco-products in terms of, for instance, cost or energy savings, improved product quality and durability or reduced health impacts encourage eco-innovations. As such, customer benefits create additional demand which prompts firms to invest in and introduce eco-innovations (Kammerer, 2009). Similarly, Doran and Ryan (2012) show that firms which believe that customers expect environmentally friendly products are also more likely to eco-innovate.

The strong environmental consciousness of customers is also a strong incentive for firms to eco-innovate. Triguero et al. (2015) show that increasing demand for green products is an important driver of eco-innovations among European SMEs. Similarly, the management literature attributes a non-negligible role to corporate social responsibility (CSR). It emphasises that societal pressure and strong demand for environmentally-friendly products and processes induce firms to eco-innovate. Kesidou and Demirel (2012) in their study of a sample of UK firms highlight that CSR plays an important but somewhat differentiated role for eco-innovation: while it is important for a firm’s decision to invest in eco-R&D, it however matters little for the level of eco-R&D.

A positive effect of a strong cost-saving motive on the part of the firm is also confirmed empirically: firms which intend to save material or energy costs are not only more likely to eco-innovate (Horbach, 2008; Horbach et al., 2012; Kesidou and Demirel, 2012) but also more willing to invest more in eco-innovative activities (Kesidou and Demirel, 2012).

In contrast, empirical evidence is mixed as concerns the role of international market outreach for eco-innovations. In general, it seems to suggest that due to fiercer competitive pressures and the need to diversify to become or remain competitive, the exposure to and presence in international markets encourages eco-innovations. For instance, Horbach (2008) finds that German manufacturing firms that predominantly sold in international markets were also more likely to eco-innovate. Similarly, Ghisetti et al. (2015) demonstrate for a large sample of European firms that exporters are more likely to eco-innovate. In contrast, De Marchi (2012) emphasises for a set of Spanish firms that exporting firms are less likely to eco-innovate.

2.1.2. Technology push factors

A variety of different technology push factors have been identified as important drivers of eco-innovations. Empirically, a firm’s technological capabilities – the particular resources needed to adopt, adapt, generate and manage technical change, including R&D investments, skills, knowledge and experience – are a key driving force behind eco-innovations. In particular, eco-innovations are more likely among firms which invest in R&D (Horbach, 2008; Horbach et al., 2012; Ghisetti et al., 2015), which invest in R&D on a continuous basis (De Marchi, 2012) and whose workforce is highly qualified (Horbach, 2008; Borghesi et al., 2011). Furthermore, R&D investments are important for a firm’s decision to enlarge its eco-innovation portfolio and expand its number of eco-innovation typologies (Ghisetti et al., 2015). Moreover, given the high degree of novelty of eco-innovations that require sizeable R&D investments, complementary investments in machinery and equipment and software are found to be necessary for successful eco-innovative activities (De Marchi, 2012; Horbach et al., 2012).

In addition to technological capabilities, the buildup of organisational capabilities and practices triggers eco-innovations. In this respect, Environmental Management Systems (EMS) – i.e. a set of processes and practices that help firms to reduce their environmental impacts and increase their efficiency – which are instrumental for the development of organisational environmental capabilities, are found to spur eco-innovations, in particular process eco-innovations (Horbach et al., 2012; Kesidou and Demirel, 2012). Furthermore, Horbach et al. (2012) show that general organisational innovations, such as new forms of labour organisation or new methods of organising business processes, are conducive to eco-innovations.

Furthermore, information is a key ingredient for innovations, particularly eco-innovations, which is a young and very dynamic technological area and whose success therefore hinges on high-quality internal and external information, stemming from, e.g., customers, suppliers, competitors, consultants, universities or research institutes but also from conferences and exhibitions, scientific journals or associations. Empirically, good access to external information and knowledge is found to spur eco-innovations, particularly eco-product and eco-organisational innovations (Triguero et al., 2013). However, the effect of external information on a firm’s eco-innovativeness differs by particular source of information and varies strongly across types of eco-innovations and countries, highlighting the importance of national systems of innovations for eco-innovative outcomes (see, e.g., Horbach et al., 2012 for Germany, Horbach et al., 2013 for a comparison between Germany and France, or Borghesi et al., 2011 for Italy).

Similarly, cooperative activities of firms are of non-negligible importance for their eco-innovativeness. Generally, such cooperations are helpful to either compensate for prevailing deficiencies in internal resources and competencies, to reduce and share the risks and/or costs associated with eco-innovations, but also to get better access to markets or to realise economies of scale and scope in eco-R&D activities. For instance, empirical evidence stresses that past R&D cooperations are more important for eco-innovations than for non-eco-innovations (Horbach et al., 2012) or that cooperations encourage the adoption of eco-innovations (Ghisetti et al., 2015) but that the choice of particular cooperation partner is pivotal to the outcome of the cooperative arrangement. In this respect, given the novelty and uncertainty surrounding the field of eco-innovations, collaborations with universities, research institutes and R&D labs are of particular importance for eco-innovation success (De Marchi, 2012; Ghisetti et al., 2015; Triguero et al., 2013).

However, contrary to Schumpeter's (1934) competition-curbs-innovation hypothesis which highlights that competition lowers the expected return from R&D and therefore tends to lower R&D efforts of firms, competition – in terms of a high risk of market entry of new competitors – tends to trigger eco-innovative efforts of firms (Horbach et al., 2012). A similar positive effect on eco-innovations is found for prevailing appropriability conditions, which help reduce the extent of knowledge spillovers and therefore induce firms to more strongly engage in eco-innovative activities (Horbach et al., 2013).

2.1.3. Public policy: regulations and subsidies

From a theoretical point of view, there is generally a strong need for regulations in order to stimulate eco-innovative activities of firms. This results from the peculiarities of eco-innovations in terms of cost-saving and earnings potentials and the dual externality issue associated with eco-innovation. In particular, Porter and van der Linde highlighted that *'…properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them*' (1995:98). Accordingly, as a result of their lacking experience with environmental matters, entrepreneurs are unable to recognise the cost-saving potential of environmental innovations and therefore fail to realise environmentally and economically beneficial innovations. Hence, environmental regulations are strongly needed which, in turn, help create win-win situations: regulations induce entrepreneurs to invest in environmental R&D to comply with environmental regulation standards and, at the same time, enable them to reduce their production costs, increase their profits and competitiveness or enter markets for eco-products. Furthermore, the need for regulation is also emphasised by the so-called 'double externality problem' inherently connected to eco-innovations. Particularly, eco-innovations produce two types of positive externalities, (i) knowledge externalities and (ii) externalities due to the positive impact on the environment. Hence, in the face of this double market failure, characterised by private returns to R&D falling short of their social returns, firms tend to underinvest in R&D. This justifies or even necessitates the use of policy instruments like regulations to realise the socially desirable level of investment in eco-innovations. These are all examples of the 'weak' version of the Porter hypothesis. Van Leeuwen and Mohnen (2017) also test the validity of the 'strong' version of the Porter hypothesis through the effects of regulation on productivity in Dutch manufacturing firms. They find evidence of the productivity-enhancing effect of regulation but only for process-integrated eco-innovations.

Empirically, there is strong evidence which underscores the importance of regulations for eco-innovative activities. In particular, in line with and in support of the Porter-hypothesis, more stringent regulations are found to strongly encourage firms to eco-innovate (Doran and Ryan, 2012; Horbach, 2008; Horbach et al., 2012; Horbach et al., 2013; Kammerer, 2007). However, the effect of regulations tends to differ by the type of environmental impact and environmental innovation which highlights that regulations are not able to stimulate all different types of eco-innovation equally. Specifically, as suggested by Horbach et al. (2012) on the basis of the German Mannheim Innovation Panel, current and future regulations induced German entrepreneurs to reduce air emissions (CO_2 and other air emissions) as well as water or noise emissions, avoid hazardous substances and increase the recyclability of material, waste and water. Furthermore, future (expected) regulations help trigger eco-innovation which reduce energy consumption, emissions and pollutions and increase the recyclability of products. Furthermore, empirical evidence also points to differences across firm size. As highlighted by Triguero et al. (2013) for a large set of European SMEs, existing regulations trigger both product and organisational eco-innovation, while they fail to stimulate process eco-innovation among SMEs.

However, while a generally positive regulation-push effect is observable for a firm's decision to eco-innovate, still very little is still known about the role of (stringent) regulations for the intensity of eco-innovations. One notable exception is the study by Kesidou and Demirel (2012) for a set of British manufacturing firms which shows that while the stringency of environmental regulations is of little relevance for a firm's probability to eco-innovate, it however, strongly matters for the amount of resources allocated to eco-innovative activities, inducing entrepreneurs to spend more on environmental innovations. This suggests that regulations are also an important determinant of the resources spent on eco-innovative activities. However, this positive regulation-push effect only holds for firms with very little and very high investments in eco-innovations.

In addition to regulations, public policies, in general, and environmental policies, in particular, are important for eco-innovation. In this context, easy access to subsidies and fiscal incentives are expected to facilitate and encourage eco-innovations. In general, empirically there is no consistent positive effect of subsidies. While general public support produces mixed results, failing to generate the desired positive effect at times (Horbach et al., 2013; Triguero et al., 2013), environmental public support for eco-innovation helps trigger eco-innovations (Ghisetti et al., 2015). This positive environmental policy effect however differs by the type of technology impact and appears most relevant for the reduction of CO_2 and other air emissions and the reduction of energy use and air, water, soil and noise pollution during after-sale-consumption (Horbach et al., 2012).

2.1.4. Firm characteristics

Studies on environmental innovation highlight that eco-innovations are also driven by several structural firm-specific characteristics. In particular, firm size matters: in support of Schumpeter's (1942) positive firm size-innovation hypothesis which emphasises the difficulty of smaller firms in raising external capital due to capital market imperfections, larger firms are found to be consistently more likely to eco-innovate (Horbach, 2008; Horbach et al., 2012; Horbach et al., 2013; De Marchi, 2012; Kesidou and Demirel, 2012; Triguero et al., 2013).

In contrast, firm age seems to play no significant role for eco-innovations (Horbach, 2008; Horbach et al., 2012). Hence, there is neither support of Arrow's (1962) positive age-innovation hypothesis which stresses that as a result of learning-by-doing, older firms tend to be more knowledgeable, efficient and innovative, nor of Agarwal and Gort's (1996 and 2002) negative age-innovation hypothesis which emphasises the role of organisational rigidities, rendering firms inflexible and rigid and unresponsive to frequently changing market conditions as they grow older.

Furthermore, affiliation to either a domestic or a foreign parent company produces mixed empirical results. For instance, Ghisetti et al. (2015) show that affiliation to a multi-national corporation is advantageous, encouraging subsidiaries to adopt eco-innovations as well as to expand their portfolio of different types of eco-innovations. In contrast, De Marchi (2012) fails to find any significant effect of a subsidiary's affiliation to either a domestic or foreign parent company on eco-innovative activities, which may be due to the parent company's preference to centralise and concentrate eco-innovative activities at the parent company.

2.2. PERFORMANCE EFFECTS OF ECO-INNOVATION

Numerous empirical studies which have looked at the effects of eco-innovations on both firms' economic as well as environmental[1] performance have found that eco-innovations exert a positive effect on firm performance.

As concerns labour productivity, Marin (2012) and Marin and Lotti (2014) use extended CDM models (Crépon et al., 1998) and demonstrate for Italian manufacturing firms that eco-innovations – as proxied by environmental patents – exert a strong positive effect on labour productivity. However, at least in the short run, environmental innovations are found to crowd out other, more profitable, non-environmental innovations. Similarly, Doran and Ryan (2012) show that Irish firms which engage in eco-innovations have higher labour productivity levels than those which either introduce non-eco-innovations or which do not engage in eco-innovations at all.

Just like regular innovations, eco-innovations also have a growth-enhancing effect. For instance, Colombelli et al. (2015) study a set of European firms and suggest that firms that produce green technologies and apply for green patents also grow faster than those which produce regular innovations. Moreover, this growth-enhancing effect of green technologies is particularly strong among gazelles.

Similarly, eco-innovations also improve firm profits. Rexhäuser and Rammer (2013) study the effects of regulation-induced relative to voluntary innovations. They show that profitability effects differ by type of innovation and technology: relative to firms which did not introduce environmental innovations, firms which introduce both regulation-induced and voluntary innovations that improve resource efficiency observe a profitability-enhancing effect. In contrast, a negative profitability-effect is observable for firms which introduce regulation-induced innovations that reduce environmental externalities only (without also increasing resource efficiency). Likewise, Lanoie et al. (2011) use firm-level data for a set of OECD countries and demonstrate that environmental R&D is associated with higher profitability.

Finally, the employment effects of innovation, in general, and of eco-innovations, in particular, have received a great amount of attention. Theoretically, eco-innovations may both create and destroy jobs, rendering the net effect an a priori unclear outcome. Whether eco-innovations create or destroy jobs depends on the type of innovation considered. Empirically, while product eco-innovations have an employment-enhancing effect, the effects of process eco-innovations are mixed and inconclusive. For instance, Horbach (2010) shows that German firms belonging to the environmental sector that improved or developed new products expanded their employment levels. Likewise, Licht and Peters (2013 and

[1] See, e.g., Cheng et al. (2014), Dong et al. (2014) or Lee and Min (2015) for studies on environmental effects of eco-innovations.

2014) shed light on the differentiated effect of different types of eco-innovations on employment. They highlight that both environmental and non-environmental product innovations have a positive employment effect in general, whereas the effect of both types of process innovations is either negative or of very little importance. Furthermore, no uniform pattern emerges as to the relative employment effects of environmental and non-environmental product innovations, stressing the importance of country-specific factors and policies for employment outcomes. A similarly mixed picture is drawn by Rennings and Zwick (2002) who show that both product and services eco-innovations create more jobs than process eco-innovations while Harabi (2000) finds a long-term positive employment effect of product innovations among European firms but no significant effect of process or organisational innovations. Likewise, Kunapatarawong and Martinez-Ros (2014) show that eco-innovators grow faster, irrespective of whether environmental innovations are introduced voluntarily or in response to regulations.

3. Methodological framework

In order to shed light on the complexity of innovation processes and to explicitly account for the different channels through which innovation inputs are transformed into performance changes, the three stage CDM model[2] has become the workhorse model in innovation studies.

The CDM model portrays three different relationships in a sequential way: the drivers and determinants of innovation inputs, the relationship between innovation input and innovation output and, finally, the relationship between innovation output and firm performance. Hence, the model also comprises three methodological steps.

The first step of the model consists of two equations that explain firm i's decision ($i = 1, \dots, N$) to invest in innovative activities (or not) and if so, how much to spend on these activities. However, since expenditures on innovative activities are only reported and observable for innovative firms, sampling is no longer random and a selection bias may be incurred if left unaccounted for. Hence, to account for this selection bias, a 2-step Heckman selection model (Heckman, 1979) is estimated, where the following selection equation describes whether a firm is doing any R&D or not:

$$Drd_i = \begin{cases} 1 & if \quad Drd_i^* = X_i'\alpha + \varepsilon_i > \bar{c} \\ 0 & if \quad Drd_i^* = X_i'\alpha + \varepsilon_i \leq \bar{c} \end{cases} \tag{1a}$$

where Drd_i is an observed binary variable that is equal to 1 if firm i spends on R&D, and 0 otherwise. Firm i spends on R&D if Drd_i^* – an unobservable latent variable which measures the propensity to innovate – is above a certain threshold level $\bar{c}$. X_i denotes a vector of explanatory variables which are relevant for the decision to invest in R&D, comprising firm size (as the exclusion restriction), being part of a domestic or a foreign group, operating on international markets, and a set of country and industry dummies. ε_i is the error term.

Then, conditional on firm $i's$ decision to invest in R&D, innovation intensity is specified as follows:

$$RD_i = \begin{cases} RD_i^* = X_i'\beta + \epsilon_i \\ 0 \quad if \quad RD_i = 0 \end{cases}, \tag{1b}$$

where RD_i^* is the unobservable latent variable which reflects R&D intensity, measured as the log of R&D expenditures per employee. Furthermore, X_i refers to a vector of explanatory variables that explain R&D intensity, comprising being part of a domestic or a foreign group, operating on international markets, engaging in different forms of R&D collaborations, such as (i) other enterprises within your enterprise group, (ii) suppliers of equipment, materials, components, or software, (iii) clients or customers from the private sector, (iv) clients or customers from the public sector, (v) competitors or other enterprises in your sector, (vi) consultants or commercial labs, (vii) universities or other higher education institutes, and (viii) government, public or private research institutes, subsidies (from (i) the regional government, (ii) the national government, or (iii) the EU), and a set of country and industry dummies. ϵ_i is the error term.

[2] Named after their authors Bruno Crépon, Emmanuel Duguet and Jacques Mairesse (Crépon et al., 1998).

For the purpose of identification, the error terms are assumed to be independently and identically distributed as bivariate normal as follows:

$$\binom{\varepsilon_i}{\epsilon_i} \sim IID \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}$$

where $\rho = Cov(\varepsilon_i, \epsilon_i)$.

The system of equations (1a) and (1b) is estimated as a generalised Tobit model by maximum likelihood. Following Griffith et al. (2006), firm size is used as exclusion restriction in equation (1a).

The second step of the model focuses on the innovation production function and analyses separately innovations and eco-innovations as follows:

$$I_i = \widehat{RD}_i\gamma + Z_i'\delta_1 + u_{1i} \quad (2a)$$

$$EI_i = \widehat{RD}_i\gamma + Z_i'\delta_1 + u_{2i} \quad (2b)$$

where I_i is a binary variable that is equal to 1 if the firm introduced either a new or improved product (or service), process, marketing or organisational innovation between 2012 and 2014, and 0 otherwise. Similarly, EI_i is a binary variable that is equal to 1 if, between 2012 and 2014, an innovator introduced an innovation with an environmental benefit (either obtained within the firm (i.e. process eco-innovation) or by the end user (i.e. product eco-innovation)), and 0 otherwise. $\widehat{RD}_i$ is the predicted innovation effort taken from equations (1a) and (1b) for the total sample of firms and therefore takes into account that firms may engage in some R&D efforts without reporting it, on the one hand, and the potential endogenous nature of innovative efforts in the innovation production function, on the other. Furthermore, Z_i denotes a vector of explanatory variables, comprising firm size, being part of a domestic or foreign group, operating on international markets, investment intensity, and a set of country and industry dummies, while u_{1i} and u_{2i} are the error terms. Methodologically, two separate probit models are estimated for equations (2a) and (2b).

Furthermore, for a more differentiated picture, at this step, the analysis also distinguishes between different process and product eco-innovations. With respect to process eco-innovations – as captured by different environmental benefits that materialise within the enterprise – the following eco-innovations are distinguished: environmental benefits which help (i) reduce material or water use per unit of output, (ii) reduce energy use or CO_2 'footprint', (iii) reduce emission in terms of air, water, noise or soil pollution, (iv) replace a share of materials with less polluting or hazardous substitutes, (v) replace a share of fossil energy with renewable energy sources, and (vi) recycle waster, water, or materials for own use or sale. With respect to product eco-innovations – as captured by different environmental benefits that occur during the consumption or use by the end user – the following eco-innovations are distinguished: environmental benefits which help (i) reduce energy use or CO_2 'footprint', (ii) reduce air, water, noise or soil pollution, (iii) facilitate recycling of product after use, and (iv) extend the product life through longer-lasting, more durable products.

Finally, the last step of the model determines the effects of the two different types of innovations on firm productivity. Based on an extended simple constant returns to scale Cobb-Douglas production function, labour productivity of innovators is determined as follows:

$$lnLP_i = \hat{I}_i\theta_1 + W_i'\theta_3 + \upsilon_{1i} \quad (3a)$$

while for eco-innovators, it is determined as follows:

$$lnLP_i = \widehat{EI}_i\theta_2 + W_i'\theta_3 + \upsilon_{2i} \quad (3b)$$

where $lnLP_i$ denotes the log of labour productivity, defined as the log of sales per employee. $\hat{I}_i$ and $\widehat{EI}_i$ are the predicted probabilities for innovations and eco-innovations, respectively, which account for the endogenous nature of both types of innovation in the production function. W_i refers to a vector of additional explanatory variables, comprising firm size, physical capital intensity, skills share and a set of country and industry dummies. Finally, υ_i is the error term. Methodologically, equations (3a) and (3b) are estimated via OLS. The list of variable definitions is available in Table A.1 in the Annex.

4. Data

The analysis uses the Community Innovation Survey (CIS), which is a survey of innovation activities in enterprises that is conducted biannually by EU Member States (as well as Norway and Iceland). In particular, it uses the latest CIS wave – the CIS-2014 pertaining to the period 2012-2014 – which, similar to the CIS-2008, includes a separate module on eco-innovations.

For the purpose of the analysis, two different datasets are used: First, the anonymised dataset available in the Safe Centre at Eurostat's premises in Luxembourg. This dataset is available for a large set of EU Member States and therefore allows to shed light on innovation activities in and across the EU. Furthermore, to account for country heterogeneity and draw a more differentiated picture across EU Member States, reporting countries were clustered into three groups, according to their score of the overall Eco-Innovation Index[3] in the Eco-Innovation Scoreboard[4] in 2012. In particular, we differentiate between (i) *eco-innovation leaders*, whose scores are considerably above the EU average, (ii) *average eco-innovation performers*, whose scores are similar to the EU average, and (iii) *countries catching up on eco-innovations*, for countries whose scores are around 85% or less compared to the EU average. Figure 1 below depicts the three country groups for 2012 (which is compatible with the time horizon of the CIS-2014) and 2017 (the latest available year in the Eco-Innovation Scoreboard) for comparative reasons. It shows that in 2012, except for Slovenia and the Czech Republic, the groups of eco-innovation leaders and average eco-innovation performers exclusively comprise old EU Member States (OMS). In contrast, except for Greece, the group of countries catching up in eco-innovation only comprises new EU Member States (NMS). However, since compiling CIS data is undertaken by the countries on a voluntary basis, CIS-2014 data are not available for all EU Member States. Hence, for the analysis, we will use the following countries and country groups: Finland (FI), Germany (DE) and Sweden (SE) as eco-innovation leaders. The Czech Republic (CZ), France (FR), Italy (IT) and Luxembourg (LU) constitute average eco-innovation performers while Bulgaria (BG), Croatia (HR), Cyprus (CY), Estonia (EE), Greece (EL), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Romania (RO), and Slovakia (SK) are all countries catching up in eco-innovation.[5]

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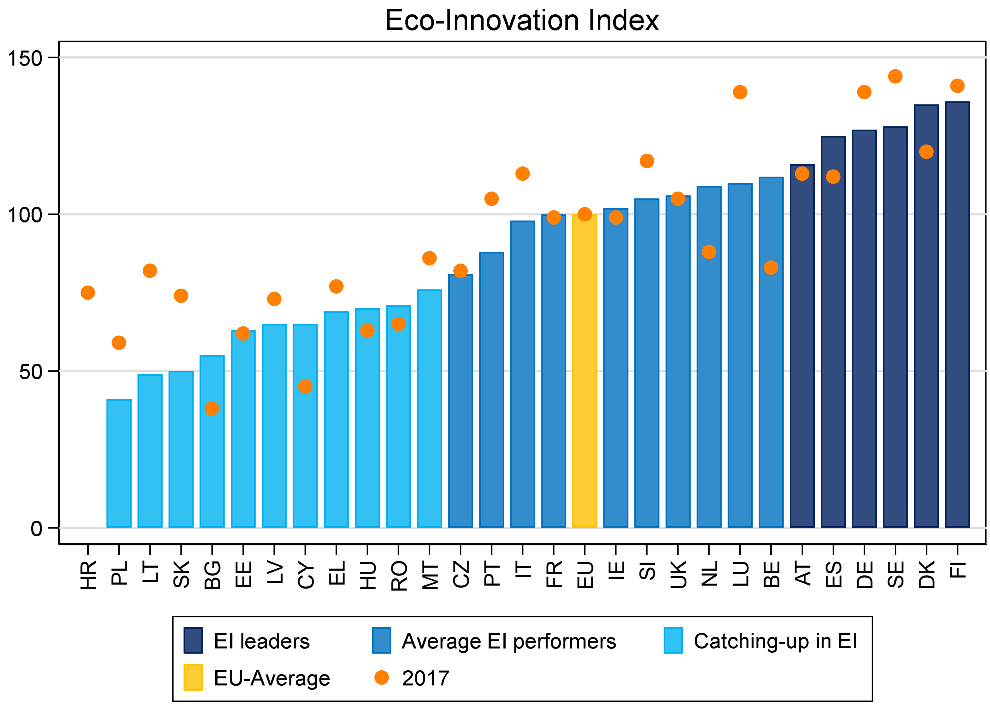
3 The Eco-Innovation Index captures the different aspects of eco-innovation by using 16 indicators grouped into five thematic areas, namely: (1) *eco-innovation inputs* (comprising governments environmental and energy R&D appropriations and outlays, total R&D personnel and researchers, and total value of green early stage investments), (2) *eco-innovation activities* (comprising the share of enterprises that introduced an innovation with environmental benefits obtained within enterprises, the share of enterprises that introduced innovation with environmental benefits obtained by the end user, and the number of ISO 14001 registered organisations), (3) *eco-innovation outputs* (comprising eco-innovation related patents, eco-innovation related academic publications, and eco-innovation related media coverage), (4) *resource efficiency outcomes* (comprising material productivity, water productivity, energy productivity, and Greenhouse Gas emissions intensity), and (5) *socio-economic outcomes* (comprising employment in eco-industries and circular economy, revenue in eco-industries and circular economy, and exports of products from eco-industries).

4 See: https://ec.europa.eu/environment/ecoap/indicators/index_en.

5 Belgium (BE) and Spain (ES) are excluded due to missing information on the eco-innovation module.

Figure 1 / Country classification according to the overall Eco-Innovation Index



Source: Eco-Innovation Scoreboard.

Second, the Mannheim Innovation Panel (MIP) for German enterprises of the Centre for European Economic Research (ZEW). As such, the German sample allows to take a closer look at one prominent member of the group of eco-innovation leaders. The use of the MIP is of benefit as it is more informative in some respects, due to its partly more comprehensive set of questions and answer options in some areas that go beyond what is specified in the harmonised CIS-2014 questionnaire. In particular, with the MIP-2014 it is possible to differentiate eco-innovations by their particular environmental benefit in terms of either high, medium, low or no environmental impact and therefore to study important motives for the introduction of eco-innovations the harmonised CIS-2014 dataset is unable to address. The analysis distinguishes between the following motives: (i) existing environmental regulations, (ii) existing environmental taxes, charges or fees, (iii) environmental regulations or taxes expected in the future, (iv) government grants, subsidies or other financial incentives for environmental innovations, (v) current or expected market demand for environmental innovations, (vi) improving the enterprise's reputation, (vii) voluntary actions or initiatives for environmental good practice within the sector, (viii) high cost of energy, water or materials, and (ix) the need to meet requirements for public procurement contracts. Furthermore, it tests for the role played by the enterprise's competitive environment for its decision whether or not to conduct any R&D and if so, how much to spend on R&D activities. In particular, the competitive environment is captured by whether (i) products/services quickly become obsolete, (ii) the technological development is difficult to predict, (iii) products/services can easily be replaced, (iv) there is threat of market entry of competitors, (v) the development of demand difficult to predict, and (vi) there is strong competition from abroad.

5. Results

5.1. INNOVATION INPUT

Results for the first stage of the CDM model which determines the innovation input are reported in Table A.3 in the Annex for the total sample (columns (1) and (2)), the three groups of eco-innovators (columns (3)-(8)) and Germany (columns (9) and (10)). The odd columns refer to the probability of being an innovator while the even columns refer to the amount of innovation input, as captured by the amount of R&D expenditure per employee.

In line with related empirical evidence which identifies firm size as one of the major determinants of the propensity to do R&D[6], the probability of being an innovator increases with firm size. The effect appears somewhat stronger in the group of average eco-innovator countries and catching-up eco-innovator countries than in countries leading in eco-innovation, though.

Moreover, being a member of a group – particularly of a domestic group – increases the probability of being innovative. This finding is in line with the literature and suggests that firms which belong to a group tend to benefit from intra-group knowledge spillovers, easier access to internal capital markets and finance or other synergies in areas like marketing or distribution, which also renders them more likely to do R&D (e.g., Mohnen et al., 2006; Hall et al., 2009; Goya et al., 2013). For the group of average eco-innovation countries and catching-up eco-innovation countries, both domestic and foreign group-membership are associated with a higher probability of being innovative. However, in both country groups, the group-membership effect is considerably stronger among members of domestic groups than foreign groups. In general, firms located in countries catching-up in eco-innovation seem to profit the most from group-membership, though.

Furthermore, a firm's market orientation matters for the occurrence of innovations.[7] As a result of fiercer competition and the need to innovate to stay competitive and survive, firms which operate in international markets – as compared to those catering to domestic markets only – are more likely to be innovative. This competition-induced effect is strongest in the group of eco-innovation leading countries but weakest in the group of countries catching-up in eco-innovation.

For the German sample, a set of additional drivers for innovation are available which describe the competitive environment of firms. Results for Germany show that some characteristics of the competitive environment matter. In particular, firms are more likely to be innovative if their competitive environment is characterised by products and services which quickly become obsolete or by an environment where technological developments are uncertain and therefore difficult to predict.

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6 See, e.g., Benavente (2002), Brown and Guzmán (2014), Crépon et al. (1998), Griffith et al. (2006), Hall et al. (2009), Janz et al. (2003), Lööf et al. (2001), Mairesse and Robin (2009) or Mohnen et al. (2006).

7 This competition-spurs-innovation effect is also found in Goya et al. (2013), Griffith et al. (2006), Janz et al. (2003) or Lööf et al. (2001).

Furthermore, R&D expenditures (per employee) are generally higher among firms that are members of groups, irrespective of whether the groups are domestic or foreign. This is suggestive of the potentially easier access to group-internal funds for R&D as highlighted by Mohnen et al. (2006) or Hall et al. (2009). However, the amount spent on R&D differs across country groups. For the group of countries leading in eco-innovation, R&D expenditures are higher for firms that are part of a domestic group. In contrast, the opposite is true for the other two country groups, where R&D expenditures are higher in firms that are part of a foreign group.

In line with other empirical findings (see, e.g., Goya et al., 2013; Griffith et al., 2006 or Mairesse and Robin, 2009), a firm's market orientation is also an important determinant of its R&D expenditures. The results indicate that the fiercer competition in international markets also induces firms to spend more on R&D than firms which operate in domestic markets only. This competition-induced spending effect is highest among firms in the group of average eco-innovation countries.

The amount spent on R&D is also related to the financial support received from the government. Generally, firms spend more on R&D if they receive public financial support which makes public R&D programmes an important determining factor of private R&D efforts. This positive effect of public funding for R&D is also emphasised by Goya et al. (2013), Hall et al. (2009) or Klomp and van Leeuwen (2001). However, the amount of R&D expenditures depends on the level of the supporting government: R&D expenditures are highest if financial support comes from the central government, followed by the EU, but lowest if it is provided by regional or local authorities. The strong importance of central government support also holds for the group of average eco-innovators and for countries catching-up on eco-innovation. In contrast, for the group of eco-innovation leaders, EU support is more important than central government support, leading to higher R&D expenditures.

Furthermore, the amount spent on R&D depends on the type of cooperation partner for innovation. For the whole sample, cooperations with suppliers are related to lower R&D expenditures while cooperations with other enterprises within the group, competitors, consultants, universities or (government, public or private) research institutes are associated with higher R&D expenditures. However, the types of cooperation partners play different roles across country groups. In the group of eco-innovation leaders, only cooperations with consultants are associated with higher R&D expenditures. In contrast, in the group of average eco-innovators, effects of innovation cooperations are similar to those of the overall sample. In the group of countries catching-up in eco-innovation, cooperative activities which enhance R&D spending are more selective and positive for cooperations with other enterprises within the group, competitors and universities.

Finally, for German firms, the competitive environment also matters for the amount spent on R&D. R&D expenditures are higher in an environment where products/services quickly become obsolete which appears to encourage firms to invest more in R&D to stay ahead of obsolescence. In contrast, R&D expenditures are lower in an environment where products/services can easily be replaced which indicates that the higher risk of replacement stemming from stronger competition discourages R&D investment activities.

5.2. INNOVATION OUTPUT

Results for the second stage of the CDM model which determines separately the introduction of innovations, in general, and eco-innovations, in particular, are reported in Table A.4 in the Annex. Again, results are reported for the total sample (columns (1) and (2)), the three groups of eco-innovators (columns (3)-(8)) and Germany (columns (9) and (10)). The odd columns refer to innovations, in general, while even columns refer to eco-innovations.

In general and in line with related empirical evidence, innovation output – of both general and eco-innovations[8] – is predominantly determined by R&D intensity. For innovation in general, the associated parameter values suggest that a one per cent increase in R&D expenditures increases the probability of a (product, process, marketing or organisational) innovation by around 6 percentage points. For eco-innovation, the effect is almost four times stronger: a one per cent increase in R&D expenditures increases the probability of a (product, process, marketing or organisational) eco-innovation by 21 percentage points. The role of R&D expenditures is, however, more differentiated across country groups. For the group of countries leading in eco-innovation, the effect of an increase in R&D expenditures is slightly stronger for innovation, in general, than for eco-innovation. In contrast, for the group of countries catching-up in eco-innovation, an increase in R&D expenditures only has a positive effect on the probability of an eco-innovation, while the probability of an innovation even decreases. With a reduction of only 1 percentage point, the effect is however rather limited. Generally, the coefficient values suggest that R&D expenditures have the strongest effect on eco-innovation in countries with average eco-innovation performance but the relative weakest effect in countries catching-up in eco-innovation. The latter is reflective of prevailing inefficiencies in the eco-innovation production process and of insufficient innovation capabilities among firms located in countries catching-up in eco-innovation.

Furthermore, firm size plays a differentiated role for the two types of innovation. For the overall sample, larger firms are less likely to introduce an innovation but more likely to introduce an eco-innovation. This negative size-innovation nexus is also observable for the group of countries leading in eco-innovation. In contrast, in the group of countries catching-up in eco-innovation, larger firms are consistently more likely to innovate, irrespective of the type of innovation. Among countries with average eco-innovation performance, size also plays a selective role, where larger firms are more likely to eco-innovate (but equally likely to innovate than smaller firms). The generally positive size-eco-innovation relationship is in line with what is typically observed in the literature.[9]

Interestingly, group-membership is negatively related to the probability of innovation and eco-innovation which seems to indicate that innovative activities (eco- and otherwise) and the necessary capabilities are still concentrated at the parent company. For the overall sample, only firms that are part of a domestic group are less likely to innovate. However, the role of group-membership differs across country groups but is generally negative (or insignificant) for eco-innovation which indicates that group membership is not beneficial to eco-innovation. For the group of countries leading in eco-innovation, being a member of a group – either domestic or foreign – reduces the probability of introducing an innovation, in general, and an eco-innovation, in particular. Hence, the notion that innovative activities and capabilities are concentrated at the parent company (domestic or foreign) is particularly true for firms located in

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8 See, e.g., Horbach (2008), Horbach et al. (2012) or Ghisetti et al. (2015).

9 See, e.g., Horbach (200), Horbach et al. (2012), Horbach et al. (2013), De Marchi (2012), Kesidou and Demirel (2012) or Triguero et al. (2013).

countries leading in eco-innovation. For the other two groups, group-membership plays different roles. For the group of average eco-innovating countries, domestic group membership renders firms less likely to eco-innovate while foreign group membership makes them more likely to innovate. A similar pattern is also observable for the group of countries catching-up in eco-innovation. While domestic group membership renders firms more likely to innovate, in general, but less likely to eco-innovate, only foreign group membership has a statistically significant effect on innovation, in general, making it more likely.

A firm's market orientation is also a determinant of innovation success: In general, firms which operate in international markets – as compared to firms which cater to domestic markets only – are less likely to introduce any type of innovation (eco- and otherwise). Hence, there is no proof of the notion that fiercer competition in international markets encourages/necessitates innovation (eco- and otherwise) (as, e.g., suggested by Horbach, 2008 or Ghisetti et al., 2015). The parameter values of the coefficients suggest that this effect is considerably stronger for eco-innovation, though. By and large, this negative effect of market orientation is also observable for the three country groups and is most consistent for eco-innovation.

Investment intensity (fixed capital investments per employee) plays a somewhat mixed role. For the sample as a whole, no significant relationship between investment intensity and the introduction of any type of innovation (eco- and otherwise) can be detected. However, effects are mixed for the three country groups. For the group of countries leading in eco-innovation, more fixed capital investments (per employee) are associated with a lower likelihood of introducing any type of innovation (eco- and otherwise). In contrast, for the other two country groups, due to the need for complementary investments (in, e.g., machinery and equipment (M&E) or software) for successful eco-innovation, a higher investment intensity makes firms more likely to eco-innovate. The differentiated results across country groups may point to the presence of decreasing returns to investments: in countries leading in eco-innovation, complementary M&E and software is probably already in place so that additional investments not necessarily increase the probability of another eco-innovation. In contrast, in countries with average eco-innovation performance or countries catching-up in eco-innovation, further investments are needed to install the necessary additional physical infrastructure to enable eco-innovation in the first place.

Furthermore, for the German sample, a closer look at additional important drivers for the introduction of eco-innovation was possible.

For instance, similar to findings in Horbach (2008) or the Flash Eurobarometer (2011), current or expected future demand is a key driver of eco-innovation. From a policy point of view, this finding underscores the importance of targeted demand-side policies to guarantee high and growing demand for eco-innovation. Similarly, voluntary actions on the part of the firm or existing industry-specific standards, rising costs for energy and other resources or improving the firm's reputation – and ultimately the demand for its products and services – are also strong incentives towards the development and introduction of eco-innovation. The strong cost and resource saving motive is also highlighted in the literature (see, e.g., Horbach, 2008; Horbach et al., 2012 or Kesidou and Demirel, 2012).

In contrast, results suggest that public policy plays a limited role. For instance, firms are more likely to introduce eco-innovation if they received public financial support. However, in contrast to what is typically found in the literature[10], there is no evidence in support of the so-called Porter hypothesis (Porter and van der Linde, 1995) which emphasises that environmental regulations are strongly needed to induce entrepreneurs, who lack experience with environmental matters and are unable to recognize the cost-saving potential of environmental innovations, to realise environmentally and economically beneficial innovations. Particularly, results highlight that neither current nor future regulations for eco-innovation are able to induce firms to introduce any eco-innovation. The statistically insignificant effect of present regulations is probably due to the fact that after 2010 no major new environmental regulations were introduced in Germany. Hence, there was also little incentive for firms to adjust to comply with stricter environmental regulations. In a similar vein, existing environmental taxes or fees also fail to induce firms to eco-innovate.

5.2.1. Innovation output: a closer look at individual eco-innovations

To draw a more comprehensive and differentiated picture, the analysis also looks at the different types of eco-innovation and their determinants (see Table A.6 to Table A.10 for the different country samples). The analysis distinguishes between different environmental process and product innovations in terms of their environmental benefit.

In line with findings for all eco-innovations, R&D intensity is a key determinant of eco-innovation, irrespective of type of eco-innovation or country group considered. Furthermore, a comparison of coefficients shows that R&D intensity is quantitatively most important for process and product eco-innovation which reduce energy/CO_2 use. In contrast, R&D intensity is quantitatively least important for process eco-innovation which replace a share of fossil energy with renewable energy sources as well as for process and product eco-innovation which increase and facilitate recycling of waste, water, or other materials and the final product after use.

In a similar vein, the importance of firm size is also apparent for all different types of eco-innovations and across all country groups considered. The size of the coefficients suggests that larger firms are more likely to introduce process eco-innovations, particularly process eco-innovations which result in a reduction of energy use or of the CO_2 footprint. In contrast, larger firms are generally less likely to introduce product eco-innovations, particularly those which facilitate recycling of the product after use or which extend the product life through longer-lasting and more durable products. These types of product eco-innovations are therefore more likely and prevalent among smaller firms.

Furthermore, group membership – whether in a domestic or foreign group – is negatively related to the occurrence of the different types of eco-innovations. With some exceptions (particularly for firms located in the group of eco-innovation leading countries), this patterns is consistent across country groups. Furthermore, a comparison of the coefficients suggests that eco-innovations are somewhat less likely for firms that are part of a domestic group than a foreign group.

Operating in international markets is also associated with a lower occurrence of both process and product eco-innovations, which generally holds for all country groups. Furthermore, the relative size of the coefficients suggests that firms which operate in international markets – as opposed to those which

10 See, e.g., Doran and Ryan (2012), Horbach (2008), Horbach et al. (2012), Horbach et al. (2013) or Kammerer (2007).

operate in domestic markets only – are least likely to introduce process and product eco-innovations which lead to a reduced energy use or CO_2 footprint.

Investment intensity also plays a somewhat mixed role for the different types of eco-innovations. In general, results suggest that complementary fixed capital investments (i.e. M&E, software etc.) are important for eco-innovations, but not for all different types of eco-innovations and not in all country groups. For instance, in the group of eco-innovation leaders, additional fixed capital investments are statistically unrelated to any type of eco-innovation. For firms located in countries with average eco-innovation performance, more fixed capital investments help spur the majority of process eco-innovation but either have no (statistically significant) effect or even a negative effect on product eco-innovations. The latter is true for product eco-innovations which result in an extended product life through longer-lasting and more durable products. In contrast, more fixed capital investments are important for any type of process or product eco-innovation, with the exception of product eco-innovations which result in an extended product life through longer-lasting and more durable products. Quantitatively, the effect of additional investments is strongest for process eco-innovations which help reduce emissions (through lower air, water, noise or soil pollution) and energy use or CO_2 footprint or increase recycling of waste, water or other materials.

Results for the German sample also help shed light on additional drivers of eco-innovation related to, among other things, demand and demand expectations, taxes and charges, environmental regulations and energy costs.

For instance, present and future expected demand are a key driving force behind all product eco-innovations but also some selected process eco-innovations such as those which lead to lower material and water use, reduced water or soil pollution and the replacement of fossil energy with renewable energy sources. To improve a firm’s reputation is little incentive for the introduction of eco-innovations. The only notable exceptions concern eco-innovations which reduce CO2 emissions and air pollution or facilitate recycling of products after use. In contrast, voluntary actions or industry-specific standards trigger the majority of eco-innovations, particularly product eco-innovations. As expected, rising energy costs are a particularly strong incentive towards process and product eco-innovations which reduce energy use.

Interestingly, an analysis of the role of public policy for the different types of process and product eco-innovations points to important differences. For instance, present regulations only help trigger eco-innovations which reduce air emissions or replace dangerous substances. Future regulations/taxes spur almost all types of process and product eco-innovations but are quantitatively most important for process eco-innovations which reduce CO2 emissions or replace fossil energy sources with renewable ones. Present taxes or charges only matter for product eco-innovation which facilitate recycling of products after use. Public financial support matters for very few eco-innovations only, most notably for process and product eco-innovations which help reduce energy use.

5.3. PRODUCTIVITY

Table A.5 in the Annex reports results as concerns the productivity effects of innovations, in general, and eco-innovation, in particular. Again, results are reported for the five different country samples and for innovation and eco-innovation separately. Furthermore, to better bring out the heterogeneous nature of eco-innovation, they are further broken down into individual types of eco-innovation. Results in columns (1)-(3) refer to the total sample, columns (4)-(12) to the three country sub-samples and columns (13)-(16) to Germany.

The results show that, in line with related empirical evidence, the productivity effects of eco-innovations are generally positive (see, e.g., Marin, 2012; Marin and Lotti, 2014 or Doran and Ryan, 2012). However, there are some exceptions. For instance, for the overall sample, innovation is unrelated to labour productivity. Moreover, for the group of countries leading in eco-innovation, both innovation and eco-innovation are associated with lower labour productivity. However, eco-innovations have a considerably lower productivity-enhancing effect than innovations in general.

Once, the different types of eco-innovation are distinguished, a more differentiated picture emerges, with both positive and negative effects. As is obvious from Table A.5, no clear pattern emerges as concerns the productivity effects across country groups which indicates that productivity effects of eco-innovation not only depend on the particular type of eco-innovation but also the country group and prevailing national systems of innovation.

Finally, labour productivity is also associated with particular firm-specific characteristics. For instance, larger, more capital firms with a more skilled labour force are more productive.

6. Summary and conclusion

Eco-innovation has been put at the heart of the Europe 2020 strategy for smart, sustainable and inclusive growth due its potential to address some of the EU's current environment-related societal challenges and to improve the EU's competitiveness, productivity and growth.

In this context, the paper analyses drivers of and barriers for eco-innovation and determines the effects of eco-innovation on competitiveness, as captured by labour productivity. It looks at (product, process, marketing or organisational) innovation, in general, in comparison to (product, process, marketing or organisational) innovation with an environmental benefit – referred to as eco-innovation – to identify potential differences. In addition, eco-innovations are further distinguished in terms of different process and product eco-innovations with the aim to identify their particular drivers, barriers and effects. The analysis uses firm-level data from the CIS-2014 (for the years 2012-2014) as well as the German MIP-2014. To better bring out differences across EU countries, the EU-wide sample is further split up into three country samples reflective of their relative eco-innovation performance in terms of (i) eco-innovation leaders, (ii) average eco-innovation performers, and (iii) countries catching-up in eco-innovation. The MIP sample is of great interest as it allows to shed light on additional drivers related to demand or public policy the standardised CIS is unable to address.

The results show that investments – either in terms of expenditures for R&D or of complementary fixed capital investments for the acquisition of machinery, equipment, software, buildings – are key drivers of eco-innovations. However, both types of investments play different roles in the three country groups. R&D expenditures have the relative strongest eco-innovation-enhancing effect in the group of countries with average eco-innovation performance. However, R&D expenditures have the relative weakest effect in countries catching-up in eco-innovation which points to inefficiencies in the eco-innovation production process and insufficient innovation capabilities among firms located in these countries. Fixed capital investments are particularly important in countries with average eco-innovation performance and countries catching-up in eco-innovation where further investments into the insufficient physical infrastructure helps boost eco-innovations. The analysis of the German sample also highlights that expected future demand, rising costs for energy and other resources or the wish to improve one's reputation and adhere to industry standards are important drivers of eco-innovation. From a policy perspective, the strong role of demand emphasises the need for effective demand-side policies to boost the demand for and occurrence of eco-innovations. In contrast, for the German sample, public policy plays a limited role only. In particular, only public financial support helps trigger eco-innovative activities while no evidence is found in support of the Porter hypothesis (Porter and van der Linde, 1995). However, once eco-innovations are further differentiated, regulations turn out to be important but only for some particular types of eco-innovations. This selective effect of regulations suggests that they are not a one-size-fits-all type of policy tool but are effective in spurring particular types of eco-innovations. In contrast, international market orientation, which is generally considered to be an important trigger for innovation due to fiercer competition, turns out to be a barrier for eco-innovation. This finding is fairly consistent across all country groups and types of eco-innovations.

Furthermore, some particular firm characteristics are important determinants of eco-innovations. For instance, larger firms are more likely to eco-innovate. This positive size-effect is strongest for process eco-innovations and firms located in countries with average eco-innovation performance or countries catching-up in eco-innovation. In contrast, affiliation to a firm group is negatively related to eco-innovation which indicates that the necessary capabilities for eco-innovation are concentrated at the parent company. This negative relationship is consistent across country groups, particularly as affiliations to domestic groups are concerned.

Finally, with a few exceptions only, the productivity effects of eco-innovations are generally positive, which is a big incentive to undertake eco-innovative activities.

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8. Annex

Table A.1 / Variable definitions

Variable name	Definition	Source
Innovation	Dummy=1 if firm introduced either a new/improved product, process, marketing innovation or organisational innovation, 0 otherwise	CIS-2014
Eco-innovation	Dummy=1 if firm introduced eco-innovation, 0 otherwise	CIS-2014
Eco-innovation	Dummy=1 if firm introduced eco-innovation with a high environmental impact, 0 otherwise	MIP-2014
R&D intensity	Log of (internal & external) R&D expenditures per employee	CIS-2014
Size	Log of the number of employees	CIS-2014
Domestic group	Dummy=1 if firm is part of a domestic group, 0 otherwise	CIS-2014
Foreign group	Dummy=1 if firm is part of a foreign group, 0 otherwise	CIS-2014
International market	Dummy=1 if major market is outside of the country, 0 otherwise	CIS-2014
Local funding	Dummy=1 if firm received a public subsidy for R&D from the regional government, 0 otherwise	CIS-2014
National funding	Dummy=1 if firm received a subsidy for R&D from the national government (ministries), zero otherwise	CIS-2014
EU funding	Dummy=1 if firm received a subsidy for R&D from the EU, 0 otherwise	CIS-2014
Coop: other enterprises	Dummy=1 if innovation cooperation partner was another enterprise within the enterprise group, 0 otherwise	CIS-2014
Coop: suppliers	Dummy=1 if innovation cooperation partner were suppliers of equipment, materials, components, or software, 0 otherwise	CIS-2014
Coop: private clients	Dummy=1 if innovation cooperation partner were clients or customers from the private sector, 0 otherwise	CIS-2014
Coop: public clients	Dummy=1 if innovation cooperation partner were clients or customers from the public sector, 0 otherwise	CIS-2014
Coop: competitors	Dummy=1 if innovation cooperation partner were competitors or other enterprises in the same sector, 0 otherwise	CIS-2014
Coop: consultants	Dummy=1 if innovation cooperation partner were consultants or commercial labs, 0 otherwise	CIS-2014
Coop: universities	Dummy=1 if innovation cooperation partner were universities or other higher education institutes, 0 otherwise	CIS-2014
Coop: research institutes	Dummy=1 if innovation cooperation partner were government, public or private research institutes, 0 otherwise	CIS-2014
Products/services quickly become obsolete	Dummy=1 if products/services quickly become redundant (medium or high), 0 otherwise	MIP-2014
Technological development difficult to predict	Dummy=1 if technological developments are difficult to foresee (medium or high), 0 otherwise	MIP-2014
Products/services can easily be replaced	Dummy=1 if products/services can easily be replaced by similar products (medium or high), 0 otherwise	MIP-2014

ctd.

Table A.1 / ctd.

Variable name	Definition	Source
Threat of market entry of competitors	Dummy=1 if there is high threat of market entry of competitors (medium or high), 0 otherwise	MIP-2014
Development of demand difficult to predict	Dummy=1 if the development of demand is difficult to predict (medium or high), 0 otherwise	MIP-2014
Strong competition from abroad	Dummy=1 if there is strong competition from foreign competitors (medium or high), 0 otherwise	MIP-2014
Assets per employee	Log of fixed assets per employee	CIS-2014
Investment intensity	Log of fixed capital investments per employee	CIS-2014
Present regulations	Dummy=1 if the fulfilment of existing environmental regulations was of high or medium relevance, 0 otherwise	MIP-2014
Present taxes, charges or fees	Dummy=1 if existing environmental taxes, charges or fees was of high or medium relevance, 0 otherwise	MIP-2014
Future regulations/taxes	Dummy=1 if future expected environmental regulations/taxes was of high or medium relevance, 0 otherwise	MIP-2014
Public financial support	Dummy=1 if government grants/subsidies/other financial incentives for environmental innovations were of high or medium relevance, 0 otherwise	MIP-2014
Present or expected demand	Dummy=1 if current/expected demand for eco innovations was of high or medium relevance, 0 otherwise	MIP-2014
Reputation	Dummy=1 if improving the firm's reputation was of high or medium relevance, 0 otherwise	MIP-2014
Voluntary actions or standards	Dummy=1 if voluntary actions/initiatives for environmental good practice in the firm's sector was of high or medium relevance, 0 otherwise	MIP-2014
Rising costs for energy/other resources	Dummy=1 if rising costs for energy or other resources was of high or medium relevance, 0 otherwise	MIP-2014
Investment intensity	Log of fixed capital investment per employee	CIS-2014
Skills share	Share of workforce with tertiary education (%)	MIP-2014
Labour productivity	Log of sales per employee	CIS-2014
East	Dummy=1 if firm located in the East of Germany, 0 otherwise	MIP-2014
Country	Dummy for each country	CIS-2014
Industry	Dummy for each 2-digit industry	CIS-2014

Table A.2 / Summary statistics

Variable	Obs.	Eco leaders Mean; SD (Min; Max)	Obs.	Average Eco Mean; SD (Min; Max)	Obs.	Eco catching-up Mean; SD (Min; Max)
Eco-innovation	16855	0.38; 0.49 (0; 1)	34154	0.29; 0.46 (0; 1)	55184	0.15; 0.36 (0; 1)
Innovation	16855	0.56; 0.50 (0; 1)	34154	0.54; 0.50 (0; 1)	55184	0.33; 0.47 (0; 1)
Size	16855	4.05; 1.55 (0; 11.98)	34154	3.86; 1.43 (2.30; 12.41)	55097	3.59; 1.17 (0; 10.35)
International markets	16855	0.50; 0.50 (0; 1)	34154	0.52; 0.50 (0; 1)	55184	0.54; 0.50 (0; 1)
Coop: other enterprises	10661	0.14; 0.35 (0; 1)	25826	0.11; 0.31 (0; 1)	14612	0.12; 0.32 (0; 1)
Coop: suppliers	10661	0.17; 0.38 (0; 1)	25826	0.12; 0.33 (0; 1)	14612	0.22; 0.42 (0; 1)
Coop: public clients	10661	0.16; 0.36 (0; 1)	25826	0.06; 0.24 (0; 1)	14612	0.13; 0.33 (0; 1)
Coop: private clients	10661	0.08; 0.26 (0; 1)	25826	0.03; 0.16 (0; 1)	14612	0.04; 0.20 (0; 1)
Coop: competitors	10661	0.10; 0.30 (0; 1)	25826	0.05; 0.21 (0; 1)	14612	0.07; 0.26 (0; 1)
Coop: consultants	10661	0.13; 0.34 (0; 1)	25826	0.09; 0.29 (0; 1)	14612	0.10; 0.30 (0; 1)
Coop: universities	10661	0.17; 0.37 (0; 1)	25826	0.10; 0.29 (0; 1)	14612	0.11; 0.31 (0; 1)
Coop: research institutes	10661	0.12; 0.33 (0; 1)	25826	0.06; 0.23 (0; 1)	14612	0.06; 0.24 (0; 1)
Domestic group	16855	0.26; 0.44 (0; 1)	34154	0.36; 0.48 (0; 1)	55184	0.12; 0.32 (0; 1)
Foreign group	16855	0.35; 0.48 (0; 1)	34154	0.12; 0.33 (0; 1)	55184	0.12; 0.32 (0; 1)
Local support	8461	0.08; 0.26 (0; 1)	14980	0.15; 0.35 (0; 1)	14418	0.04; 0.19 (0; 1)
Government support	8461	0.21; 0.41 (0; 1)	14980	0.17; 0.38 (0; 1)	14419	0.18; 0.38 (0; 1)
EU support	8461	0.09; 0.28 (0; 1)	14980	0.10; 0.30 (0; 1)	14417	0.17; 0.37 (0; 1)
R&D innovator	16855	0.37; 0.48 (0; 1)	34154	0.26; 0.44 (0; 1)	55184	0.11; 0.32 (0; 1)
Log R&D intensity	7171	8.08; 1.82 (-0.97; 15.27)	8388	7.64; 1.88 (-2.48; 13.50)	5069	6.82; 1.94 (-7.52; 12.5)
Log investment intensity	11145	4.89; 3.61 (-2.13; 14.38)	14933	4.53; 3.30 (-2.71; 13.59)	12308	4.27; 3.24 (-7.52; 12.77)
Tertiary degree	5226	2.62; 1.76 (0; 6)	18311	1.79; 1.88 (0; 6)	52693	2.55; 1.84 (0; 6)
PC: Material/water	9454	0.28; 0.45 (0; 1)	18517	0.24; 0.43 (0; 1)	18063	0.20; 0.40 (0; 1)
PC: Energy/CO_2	9466	0.42; 0.49 (0; 1)	18517	0.32; 0.47 (0; 1)	18066	0.23; 0.42 (0; 1)
PC: Emission	9450	0.29; 0.45 (0; 1)	17424	0.25; 0.43 (0; 1)	18067	0.20; 0.40 (0; 1)
PC: Dangerous substances	9447	0.24; 0.42 (0; 1)	17472	0.23; 0.42 (0; 1)	18065	0.17; 0.38 (0; 1)
PC: Fossil energy	9454	0.16; 0.37 (0; 1)	17334	0.10; 0.30 (0; 1)	18063	0.07; 0.25 (0; 1)
PC: Recycling	9460	0.28; 0.45 (0; 1)	17847	0.25; 0.43 (0; 1)	18067	0.25; 0.43 (0; 1)
PD: Energy/CO_2	9455	0.34; 0.47 (0; 1)	18517	0.24; 0.43 (0; 1)	18065	0.17; 0.38 (0; 1)
PD: Emission	9462	0.25; (0.43) (0; 1)	17024	0.19; 0.40 (0; 1)	18061	0.15; 0.36 (0; 1)
PD: Recycling	9455	0.20; 0.40 (0; 1)	17282	0.17; 0.38 (0; 1)	18060	0.16; 0.37 (0; 1)
PD: Lifetime	9456	0.21; 0.41 (0; 1)	17067	0.17; 0.37 (0; 1)	18061	0.15; 0.36 (0; 1)

Table A.3 / Innovation input – R&D intensity

Variables	Total sample		Eco leaders		Average eco		Eco catching-up		Germany	
	RDinnov	lnRDexp	RDinnov	lnRDexp	RDinnov	lnRDexp	RDinnov	lnRDexp	RDinnov	lnRDexp
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Size	0.264***		0.243***		0.284***		0.279***		0.229***	
	(60.246)		(26.605)		(43.666)		(37.523)		(13.497)	
Domestic group	0.191***	0.337***	0.082**	0.414***	0.191***	0.325***	0.308***	0.479***	0.137**	0.071
	(13.299)	(9.940)	(2.349)	(5.597)	(9.258)	(6.582)	(12.829)	(6.561)	(2.283)	(0.689)
Foreign group	0.016	0.306***	0.041	0.389***	0.048*	0.403***	0.069***	0.524***	-0.069	0.357**
	(0.969)	(7.395)	(1.134)	(4.814)	(1.706)	(6.325)	(2.673)	(6.253)	(-0.664)	(2.062)
International markets	0.558***	0.787***	0.704***	0.720***	0.617***	0.996***	0.461***	0.772***	0.684***	1.042***
	(42.621)	(19.952)	(26.020)	(9.143)	(31.304)	(17.164)	(21.754)	(9.620)	(11.791)	(7.336)
Local support		0.135***		0.163**		0.121**		0.004		0.331**
		(3.659)		(2.198)		(2.523)		(0.034)		(2.449)
National support		0.498***		0.553***		0.618***		0.562***		0.569***
		(16.135)		(8.952)		(13.222)		(9.603)		(4.881)
EU support		0.363***		0.693***		0.187***		0.381***		0.360**
		(10.030)		(9.375)		(3.262)		(5.995)		(2.360)
Coop: other enterprises		0.115***		0.002		0.232***		0.173**		0.035
		(3.008)		(0.023)		(4.312)		(2.132)		(0.231)
Coop: suppliers		-0.069*		-0.100		-0.190***		0.005		0.058
		(-1.944)		(-1.190)		(-3.770)		(0.078)		(0.440)
Coop: private clients		0.061		0.100		0.053		0.067		
		(1.621)		(1.302)		(0.918)		(0.941)		
Coop: public clients		0.051		0.032		0.114		0.055		
		(1.024)		(0.377)		(1.385)		(0.540)		
Coop: private & public clients										0.201
										(1.604)
Coop: competitors		0.071*		0.005		0.081		0.134*		-0.164
		(1.734)		(0.069)		(1.284)		(1.667)		(-0.782)
Coop: consultants		0.192***		0.419***		0.109*		0.110		-0.253*
		(4.878)		(4.945)		(1.941)		(1.399)		(-1.661)
Coop: universities		0.156***		-0.020		0.380***		0.297***		0.084
		(4.156)		(-0.253)		(6.792)		(4.160)		(0.688)
Coop: research institutes		0.146***		-0.008		0.226***		0.138		0.359***
		(3.558)		(-0.108)		(3.607)		(1.640)		(2.880)

ctd.

Table A.3 / continued

Variables	Total sample RDinnov (1)	Total sample lnRDexp (2)	Eco leaders RDinnov (3)	Eco leaders lnRDexp (4)	Average eco RDinnov (5)	Average eco lnRDexp (6)	Eco catching-up RDinnov (7)	Eco catching-up lnRDexp (8)	Germany RDinnov (9)	Germany lnRDexp (10)
Products/services quickly become obsolete									0.222***	0.538***
									(3.589)	(4.775)
Technological development difficult to predict									0.102*	0.008
									(1.903)	(0.081)
Products/services can easily be replaced									-0.083	-0.219**
									(-1.600)	(-2.265)
Threat of market entry of competitors									-0.084	-0.131
									(-1.623)	(-1.391)
Development of demand difficult to predict									0.016	0.028
									(0.308)	(0.302)
Strong competition from abroad									-0.009	0.153
									(-0.173)	(1.559)
East									0.182***	0.107
									(3.616)	(1.095)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	no	no
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant	-3.616***	2.740***	-2.315***	5.731***	-3.009***	4.057***	-3.589***	1.663***	-2.247***	-8.099***
	(-52.868)	(13.663)	(-17.232)	(16.423)	(-25.277)	(14.109)	(-34.762)	(4.687)	(-15.260)	(-20.614)
No of observations	101;390	101;390	14;217	14;217	33;602	33;602	53;571	53;571	4;243	4;243
Log likelihood	-67723	-67723	-15582	-15582	-30010	-30010	-22928	-22928	-4086	-4086
Rho	0.521	0.521	0.245	0.245	0.598	0.598	0.648	0.648	0.667	0.667
Wald test of independent equations	705.7	705.7	25.07	25.07	436.2	436.2	377.1	377.1	80.28	80.28
p-value	0	0	0	0	0	0	0	0	0	0

Robust z-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1.

Table A.4 / Innovation output: innovation and eco-innovation (EI)

	Total sample		Eco leaders		Average eco		Eco catching-up		Germany	
	Innov	EI	Innov	EI	Innov	EI	Innov	EI	Innov	EI
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
R&D intensity	0.060***	0.209***	0.199***	0.179***	0.015***	0.183***	-0.008*	0.149***	0.023**	0.056**
	(12.005)	(23.500)	(11.593)	(10.594)	(3.053)	(15.881)	(-1.744)	(10.966)	(2.177)	(1.986)
Size	-0.007***	0.034***	-0.037***	-0.007	-0.000	0.059***	0.005***	0.048***	0.014***	-0.003
	(-6.685)	(14.248)	(-10.773)	(-1.629)	(-0.027)	(16.690)	(2.871)	(10.160)	(3.566)	(-0.283)
Domestic group	-0.013***	-0.067***	-0.105***	-0.119***	0.001	-0.059***	0.018***	-0.043***	0.021	0.029
	(-3.342)	(-8.060)	(-6.840)	(-6.225)	(0.223)	(-5.049)	(3.064)	(-2.706)	(1.498)	(0.806)
Foreign group	0.006	-0.004	-0.104***	-0.087***	0.020***	-0.016	0.027***	-0.001	-0.023	0.026
	(1.268)	(-0.444)	(-5.561)	(-4.279)	(2.874)	(-1.046)	(4.267)	(-0.049)	(-1.112)	(0.456)
International markets	-0.025***	-0.154***	-0.066***	-0.091***	-0.000	-0.172***	0.008	-0.113***	-0.016	0.026
	(-4.609)	(-14.760)	(-3.706)	(-4.607)	(-0.013)	(-10.427)	(1.429)	(-6.760)	(-0.932)	(0.517)
Investment intensity	-0.001	-0.001	-0.010*	-0.027***	-0.001	0.008**	0.001	0.019***	0.001	0.030**
	(-0.805)	(-0.673)	(-1.919)	(-5.769)	(-0.709)	(2.489)	(0.652)	(5.532)	(0.193)	(2.548)
Present regulations										0.034
										(0.894)
Present taxes; charges or fees										-0.016
										(-0.349)
Future regulations/taxes										0.050
										(1.145)
Public financial support										0.102**
										(2.308)
Present or expected demand										0.163***
										(3.959)
Reputation										0.065*
										(1.770)
Voluntary actions or standards										0.126***
										(3.593)
Rising costs for energy/other resources										0.114***
										(3.637)
East									-0.007	-0.009
									(-0.621)	(-0.279)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	no	no
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No of observations	32;807	33;349	7;688	7;754	14;396	14;396	10;723	11;199	2;193	1;442
Log likelihood	-7470	-20303	-2465	-4766	-2937	-8723	-1887	-6706	-546	-845

Note: Marginal effects (at the mean) are reported.

Table A.5 / Labour productivity: innovation and eco-innovation (EI)

	Total sample			Eco leaders			Average eco			Eco catching-up			Germany			
	Innov	EI	EI	Innov	EI	EI	Innov	EI	EI	Innov	EI	EI	Innov	EI	EI-Prod	EI-Proc
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**
Innovation	0.188			-0.435*			11.920***			8.508***			1.829**			
	(1.627)			(-1.944)			(15.007)			(13.053)			(2.333)			
EI		0.330***			-1.439***			0.566***			1.645***			0.294***		
		(3.228)			(-4.168)			(2.919)			(9.745)			(2.632)		
Prod EI: Energy			-2.595***			6.275***			-4.622**			0.917			-0.392	
			(-4.240)			(3.527)			(-2.493)			(0.811)			(-1.214)	
Prod EI: Emission			-2.679***			-6.697***			9.607***			-4.889***			0.833**	
			(-3.300)			(-2.596)			(3.654)			(-4.842)			(2.003)	
Prod EI: Recycling			-4.986***			-1.617			-11.35***			-0.370			0.618*	
			(-6.978)			(-0.622)			(-8.315)			(-0.389)			(1.656)	
Prod EI: Lifetime			2.656***			-4.460**			3.986***			-1.676**			-0.702*	
			(6.583)			(-2.041)			(3.844)			(-2.246)			(-1.744)	
Proc EI: Material			6.807***			4.903**			-1.425			2.042*				-1.114**
			(14.038)			(2.241)			(-1.241)			(1.907)				(-2.153)
Proc EI: Energy/CO_2			0.554			-4.579**			-0.795			1.803*				
			(1.202)			(-2.335)			(-0.638)			(1.677)				
Proc EI: Energy																1.039**
																(2.390)
Proc EI: CO_2																0.347
																(0.591)
Proc EI: Emission			0.513			-2.175			-5.017***			-1.672*				
			(0.739)			(-0.751)			(-2.667)			(-1.840)				
Proc EI: Air																1.284*
																(1.690)
Proc EI: Water/Soil																2.277***
																(3.388)
Proc EI: Noise																-1.512*
																(-1.962)
Proc EI: Dang. subst.			0.408			3.393			3.273*			5.575***				-0.514
			(0.887)			(1.091)			(1.850)			(4.612)				(-0.919)
Proc EI: Fossil energ.			-1.743***			-2.754*			-6.708***			-5.563***				-3.096***
			(-4.850)			(-1.740)			(-7.697)			(-6.437)				(-7.087)
Proc EI: Recycling			-0.250			4.274*			8.378***			2.179***				1.080**
			(-0.480)			(1.649)			(4.269)			(3.280)				(2.192)
Size	0.108***	0.095***	-0.020	0.119***	0.128***	0.153	0.058***	0.061***	0.333***	0.056***	0.026**	-0.100***	0.051***	0.074***	0.086***	0.061***
	(21.192)	(13.588)	(-1.152)	(8.202)	(11.428)	(1.486)	(7.019)	(4.016)	(6.732)	(5.604)	(1.972)	(-3.991)	(3.178)	(5.849)	(6.179)	(3.558)
Assets/employee	0.069***	0.069***	0.073***	0.042**	0.020	0.063*	0.095***	0.081***	0.109***	0.075***	0.047***	0.075***	0.095***	0.113***	0.125***	0.107***
	(15.214)	(15.695)	(11.045)	(2.378)	(1.198)	(1.711)	(12.466)	(10.350)	(4.866)	(12.444)	(6.870)	(6.259)	(6.294)	(6.241)	(6.437)	(5.579)

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Table A.5 / continued

	Total sample			Eco leaders			Average eco			Eco catching-up			Germany			
	Innov	**EI**	**EI**	**Innov**	**EI**	**EI**	**Innov**	**EI**	**EI**	**Innov**	**EI**	**EI**	**Innov**	**EI**	**EI-Prod**	**EI-Proc**
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**
TD: 1% to < 5%	0.088***	0.084***	0.081***	0.135**	0.128**	0.158***	0.108***	0.129***	0.070**	0.092**	0.070*	0.056				
	(4.181)	(4.005)	(3.933)	(2.380)	(2.273)	(2.684)	(3.718)	(4.354)	(2.398)	(2.420)	(1.888)	(1.505)				
TD: 5% to < 10%	0.269***	0.264***	0.228***	0.274***	0.271***	0.263***	0.201***	0.242***	0.168***	0.324***	0.304***	0.288***				
	(12.355)	(12.234)	(10.684)	(5.069)	(5.022)	(4.855)	(6.751)	(7.987)	(5.618)	(8.216)	(7.868)	(7.479)				
TD: 10% to < 25%	0.444***	0.430***	0.378***	0.401***	0.398***	0.349***	0.355***	0.423***	0.319***	0.536***	0.505***	0.483***				
	(20.957)	(20.460)	(18.078)	(8.189)	(8.148)	(7.276)	(11.741)	(13.881)	(10.451)	(14.105)	(13.488)	(12.962)				
TD: 25% to < 50%	0.576***	0.556***	0.511***	0.477***	0.482***	0.430***	0.429***	0.504***	0.399***	0.728***	0.681***	0.669***				
	(22.411)	(21.996)	(20.435)	(8.028)	(8.126)	(7.355)	(10.759)	(12.406)	(9.984)	(17.246)	(16.519)	(16.327)				
TD: 50% to < 75%	0.711***	0.698***	0.658***	0.459***	0.465***	0.424***	0.500***	0.602***	0.487***	0.901***	0.854***	0.827***				
	(22.172)	(21.967)	(21.012)	(6.068)	(6.231)	(5.674)	(9.727)	(11.525)	(9.497)	(17.936)	(17.169)	(16.737)				
TD: ≥75%	0.704***	0.687***	0.625***	0.497***	0.497***	0.445***	0.512***	0.618***	0.483***	0.781***	0.734***	0.691***				
	(19.731)	(19.580)	(18.161)	(6.974)	(6.984)	(6.394)	(8.079)	(9.751)	(7.592)	(14.360)	(13.610)	(12.975)				
Skills share													0.005***	0.006***	0.006***	0.006***
													(5.388)	(4.777)	(4.767)	(4.875)
East													-0.307***	-0.344***	-0.345***	-0.324***
													(-8.302)	(-7.964)	(-7.383)	(-6.341)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no	no	no
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant	9.127***	9.203***	9.093***	11.120***	11.925***	12.455***	0.506	11.225***	10.588***	1.893***	8.884***	9.959***	-2.125***	-0.772***	-0.629***	-0.555***
	(80.691)	(116.672)	(74.954)	(50.978)	(40.135)	(21.237)	(0.677)	(62.722)	(26.167)	(3.404)	(72.793)	(49.821)	(-3.298)	(-4.820)	(-4.105)	(-3.133)
No of observations	19;455	19;931	19;916	2;701	2;701	2;701	7;083	7;083	7;083	9;671	10;147	10;132	2;052	1;357	1;273	1;236
R^2	0.475	0.470	0.493	0.305	0.309	0.342	0.276	0.252	0.295	0.383	0.373	0.390	0.288	0.318	0.320	0.356

Robust t-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1.

Table A.6 / Innovation output: by type of EI – total sample

	Environmental process innovations						Environmental product innovations			
Variables	**Material/ Water (1)**	**Energy/ CO_2 (2)**	**Emission (3)**	**Dang. Substance (4)**	**Fossil energy (5)**	**Recycling (6)**	**Energy/ CO_2 (7)**	**Emission (8)**	**Recycling (9)**	**Lifetime (10)**
R&D intensity	0.106***	0.135***	0.099***	0.096***	0.060***	0.082***	0.147***	0.115***	0.078***	0.110***
	(14.487)	(16.053)	(13.135)	(13.537)	(12.964)	(10.625)	(19.978)	(16.992)	(12.140)	(17.040)
Size	0.055***	0.078***	0.055***	0.042***	0.028***	0.046***	0.040***	0.031***	0.024***	0.012***
	(26.014)	(31.930)	(25.149)	(20.038)	(20.565)	(20.703)	(18.924)	(15.682)	(12.561)	(6.331)
Domestic group	-0.028***	-0.037***	-0.029***	-0.043***	-0.026***	-0.026***	-0.053***	-0.042***	-0.038***	-0.046***
	(-3.842)	(-4.499)	(-3.850)	(-5.982)	(-5.557)	(-3.428)	(-7.182)	(-6.197)	(-5.859)	(-6.942)
Foreign group	0.018**	-0.002	-0.010	-0.019**	-0.029***	0.002	-0.018**	-0.023***	-0.021***	-0.034***
	(2.176)	(-0.177)	(-1.154)	(-2.380)	(-5.322)	(0.293)	(-2.147)	(-3.024)	(-2.814)	(-4.578)
International markets	-0.076***	-0.112***	-0.082***	-0.073***	-0.051***	-0.057***	-0.123***	-0.098***	-0.060***	-0.073***
	(-8.218)	(-10.873)	(-8.666)	(-8.215)	(-8.615)	(-5.948)	(-13.355)	(-11.456)	(-7.509)	(-8.881)
Investment intensity	0.005***	0.012***	0.012***	0.001	0.002*	0.008***	0.002	0.005***	0.003*	-0.002
	(2.724)	(6.144)	(6.892)	(0.791)	(1.899)	(4.416)	(1.351)	(2.957)	(1.755)	(-1.318)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No of observations	29;886	29;899	29;060	29;127	28;987	29;380	29;891	28;791	28;989	28;838
Log likelihood	-15447	-16867	-14986	-14566	-9119	-15491	-15761	-13780	-13250	-13237

Robust t-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1.
Note: Marginal effects (at the mean) are reported.

Table A.7 / Innovation output: by type of EI – EI leaders

	Environmental process innovations						Environmental product innovations			
	Material/ Water	Energy/ CO_2	Emission	Dang. Substance	Fossil energy	Recycling	Energy/ CO_2	Emission	Recycling	Lifetime
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
R&D intensity	0.048***	0.063***	0.045***	0.067***	0.045***	0.028*	0.140***	0.100***	0.047***	0.081***
	(2.990)	(3.413)	(2.811)	(4.504)	(3.652)	(1.760)	(8.049)	(6.539)	(3.469)	(5.654)
Size	0.061***	0.082***	0.058***	0.045***	0.048***	0.050***	0.056***	0.040***	0.032***	0.025***
	(12.335)	(13.707)	(11.529)	(9.563)	(12.957)	(10.308)	(10.297)	(8.305)	(7.518)	(5.454)
Domestic group	-0.025	-0.022	-0.027	-0.037*	-0.030*	-0.021	-0.045**	-0.059***	-0.021	-0.053***
	(-1.293)	(-1.018)	(-1.356)	(-1.930)	(-1.912)	(-1.086)	(-2.149)	(-3.108)	(-1.207)	(-2.896)
Foreign group	0.013	-0.018	-0.032	-0.013	-0.008	-0.004	-0.026	-0.040**	-0.006	-0.018
	(0.664)	(-0.809)	(-1.568)	(-0.659)	(-0.483)	(-0.189)	(-1.237)	(-2.071)	(-0.368)	(-1.006)
International markets	-0.018	-0.073***	-0.053***	-0.050***	-0.063***	-0.017	-0.119***	-0.074***	-0.056***	-0.036*
	(-0.875)	(-3.209)	(-2.621)	(-2.601)	(-3.908)	(-0.852)	(-5.469)	(-3.786)	(-3.185)	(-1.931)
Investment intensity	0.000	0.003	0.005	-0.000	0.003	0.005	0.007	0.002	0.004	0.006
	(0.008)	(0.553)	(1.226)	(-0.063)	(0.879)	(1.151)	(1.470)	(0.422)	(0.988)	(1.382)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No of observations	5;583	5;595	5;581	5;578	5;585	5;590	5;586	5;595	5;587	5;589
Log likelihood	-3016	-3361	-3064	-2869	-2314	-3035	-3366	-3046	-2701	-2883

Robust t-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1.
Note: Marginal effects (at the mean) are reported.

Table A.8 / Innovation output: by type of EI – average EI performers

	Environmental process innovations						Environmental product innovations			
Variables	**Material/ Water (1)**	**Energy/ CO_2 (2)**	**Emission (3)**	**Dang. Substance (4)**	**Fossil energy (5)**	**Recycling (6)**	**Energy/ CO_2 (7)**	**Emission (8)**	**Recycling (9)**	**Lifetime (10)**
R&D intensity	0.106***	0.127***	0.097***	0.101***	0.048***	0.076***	0.155***	0.126***	0.079***	0.119***
	(11.242)	(11.769)	(9.874)	(10.677)	(7.944)	(7.897)	(16.448)	(14.278)	(9.783)	(14.571)
Size	0.057***	0.085***	0.063***	0.049***	0.030***	0.050***	0.039***	0.034***	0.028***	0.012***
	(18.561)	(24.352)	(19.377)	(15.695)	(14.759)	(16.084)	(12.606)	(11.555)	(10.012)	(4.217)
Domestic group	-0.030***	-0.055***	-0.033***	-0.058***	-0.028***	-0.028***	-0.064***	-0.050***	-0.059***	-0.055***
	(-2.869)	(-4.748)	(-3.048)	(-5.497)	(-4.123)	(-2.637)	(-6.145)	(-5.108)	(-6.379)	(-5.897)
Foreign group	0.019	-0.021	-0.012	-0.044***	-0.061***	-0.013	-0.014	-0.028**	-0.046***	-0.047***
	(1.495)	(-1.454)	(-0.884)	(-3.409)	(-6.864)	(-0.967)	(-1.089)	(-2.266)	(-4.072)	(-4.091)
International markets	-0.099***	-0.133***	-0.099***	-0.094***	-0.047***	-0.071***	-0.165***	-0.124***	-0.084***	-0.098***
	(-6.689)	(-8.144)	(-6.553)	(-6.421)	(-4.925)	(-4.787)	(-11.362)	(-9.051)	(-6.621)	(-7.604)
Investment intensity	0.006**	0.016***	0.015***	0.001	0.001	0.009***	-0.004	0.002	0.001	-0.007***
	(2.112)	(5.291)	(5.303)	(0.230)	(0.307)	(3.286)	(-1.481)	(0.849)	(0.399)	(-2.934)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No of observations	13;617	13;617	12;805	12;862	12;728	13;103	13;617	12;510	12;718	12;563
Log likelihood	-7167	-7832	-6656	-6751	-4034	-7027	-7490	-6040	-5814	-5740

Robust t-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1.
Note: Marginal effects (at the mean) are reported.

Table A.9 / Innovation output: by type of EI – catching-up in EI

	Environmental process innovations						Environmental product innovations			
Variables	Material/ Water (1)	Energy/CO_2 (2)	Emission (3)	Dang. Substance (4)	Fossil energy (5)	Recycling (6)	Energy/ CO_2 (7)	Emission (8)	Recycling (9)	Lifetime (10)
R&D intensity	0.092***	0.117***	0.092***	0.073***	0.048***	0.088***	0.100***	0.075***	0.053***	0.079***
	(8.934)	(10.316)	(8.805)	(7.609)	(8.526)	(7.596)	(10.442)	(8.262)	(5.632)	(8.739)
Size	0.049***	0.063***	0.040***	0.029***	0.017***	0.035***	0.030***	0.020***	0.014***	0.004
	(13.096)	(15.331)	(10.539)	(8.047)	(7.793)	(8.594)	(8.418)	(5.849)	(4.103)	(1.043)
Domestic group	-0.030**	-0.025*	-0.032**	-0.027**	-0.024***	-0.033**	-0.037***	-0.022**	-0.017	-0.029**
	(-2.332)	(-1.824)	(-2.455)	(-2.301)	(-3.285)	(-2.382)	(-3.078)	(-1.970)	(-1.456)	(-2.571)
Foreign group	-0.012	-0.011	-0.027**	-0.015	-0.025***	0.005	-0.029**	-0.023*	-0.016	-0.043***
	(-0.897)	(-0.776)	(-1.960)	(-1.159)	(-3.295)	(0.337)	(-2.261)	(-1.870)	(-1.294)	(-3.502)
International markets	-0.077***	-0.088***	-0.068***	-0.047***	-0.032***	-0.052***	-0.061***	-0.069***	-0.019	-0.038***
	(-5.604)	(-5.897)	(-4.873)	(-3.689)	(-3.947)	(-3.460)	(-4.679)	(-5.629)	(-1.554)	(-3.147)
Investment intensity	0.009***	0.016***	0.017***	0.005*	0.004***	0.013***	0.006**	0.010***	0.007***	-0.002
	(3.619)	(5.409)	(6.379)	(1.949)	(2.696)	(4.539)	(2.404)	(4.218)	(2.819)	(-0.752)
Country FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No of observations	10;686	10;687	10;674	10;687	10;674	10;687	10;688	10;686	10;684	10;686
Log likelihood	-5311	-5676	-5305	-4970	-2748	-5463	-5023	-4732	-4742	-4706

Robust t-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1.
Note: Marginal effects (at the mean) are reported.

Table A.10 / Innovation output: by type of EI – Germany

	Environmental process innovations									Environmental product innovations			
					Water/		Fossil	Dang.					
	Energy	Material	CO_2	Air	Soil	Noise	energy	Substance	Recycling	Energy	Emission	Recycling	Lifetime
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
R&D intensity	0.033	0.036**	0.039**	-0.006	0.004	-0.023*	0.035***	0.030**	-0.013	0.065***	0.017	0.026**	0.050***
	(1.393)	(2.165)	(2.315)	(-0.517)	(0.403)	(-1.659)	(2.651)	(2.571)	(-0.762)	(3.173)	(1.246)	(2.362)	(4.064)
Present regulations	0.018	0.024	0.013	0.028*	0.016	0.020	-0.027	0.028*	-0.015	0.005	0.031	-0.010	-0.014
	(0.535)	(1.059)	(0.568)	(1.822)	(1.057)	(1.101)	(-1.347)	(1.696)	(-0.648)	(0.193)	(1.519)	(-0.643)	(-0.771)
Present taxes/charges/fees	0.034	0.020	0.007	0.002	-0.006	0.003	0.001	0.002	0.016	-0.019	0.002	0.035**	-0.005
	(0.971)	(0.835)	(0.262)	(0.094)	(-0.406)	(0.179)	(0.064)	(0.112)	(0.649)	(-0.588)	(0.086)	(2.236)	(-0.275)
Future regulations/taxes	0.013	0.001	0.064***	0.037**	0.035**	0.033*	0.058***	0.018	0.046*	0.038	0.032	0.043**	0.047***
	(0.350)	(0.038)	(2.623)	(2.212)	(2.417)	(1.835)	(3.030)	(0.960)	(1.919)	(1.234)	(1.488)	(2.507)	(2.594)
Public financial support	0.093***	-0.023	0.051**	0.020	0.016	0.006	0.054***	-0.010	-0.001	0.088***	0.025	0.005	-0.009
	(2.745)	(-0.948)	(2.157)	(1.367)	(1.218)	(0.331)	(3.021)	(-0.583)	(-0.060)	(3.030)	(1.246)	(0.322)	(-0.485)
Present/expected demand	0.018	0.057**	0.017	0.015	0.045***	0.008	0.034*	0.010	0.026	0.111***	0.092***	0.043***	0.062***
	(0.529)	(2.477)	(0.729)	(1.038)	(3.277)	(0.457)	(1.854)	(0.638)	(1.127)	(3.868)	(4.525)	(2.913)	(3.521)
Reputation	0.021	0.019	0.054**	0.035**	0.001	0.015	0.022	0.025	0.029	0.027	0.002	0.029**	0.027
	(0.679)	(0.815)	(2.408)	(2.241)	(0.085)	(0.842)	(1.296)	(1.588)	(1.321)	(0.951)	(0.108)	(1.963)	(1.437)
Volunt. actions/standards	0.106***	0.067***	0.032	0.004	0.020	0.040**	-0.002	0.052***	0.084***	0.063**	0.045**	0.030**	0.048***
	(3.608)	(3.160)	(1.450)	(0.308)	(1.518)	(2.539)	(-0.096)	(3.694)	(3.986)	(2.397)	(2.400)	(2.067)	(2.928)
Rising costs for energy	0.119***	0.055***	0.024	-0.018	-0.004	-0.000	0.027	0.029*	0.028	0.083***	-0.001	-0.006	0.001
	(4.226)	(2.643)	(1.157)	(-1.268)	(-0.311)	(-0.022)	(1.608)	(1.859)	(1.344)	(3.332)	(-0.054)	(-0.428)	(0.039)
Size	0.014*	-0.007	0.008	0.006	-0.002	0.008*	0.004	-0.001	-0.009	0.005	0.000	-0.009**	-0.003
	(1.654)	(-1.124)	(1.311)	(1.522)	(-0.537)	(1.923)	(0.780)	(-0.145)	(-1.543)	(0.700)	(0.024)	(-2.025)	(-0.677)
Domestic group	0.014	-0.013	0.039*	-0.014	0.005	-0.016	-0.011	0.002	0.049**	0.027	-0.001	0.030**	-0.006
	(0.484)	(-0.618)	(1.783)	(-0.891)	(0.338)	(-0.920)	(-0.656)	(0.123)	(2.162)	(1.004)	(-0.051)	(2.050)	(-0.337)
Foreign group	-0.016	-0.012	-0.001	0.027	0.016	0.027	-0.078**	0.010	0.035	-0.001	-0.017	0.004	-0.013
	(-0.328)	(-0.353)	(-0.024)	(1.271)	(0.882)	(1.146)	(-2.465)	(0.451)	(1.049)	(-0.017)	(-0.546)	(0.155)	(-0.506)
International markets	0.028	-0.008	0.016	0.030	0.016	0.040*	-0.046*	-0.023	0.056*	-0.037	0.008	0.008	-0.026
	(0.629)	(-0.274)	(0.537)	(1.427)	(0.833)	(1.695)	(-1.926)	(-1.042)	(1.779)	(-0.975)	(0.300)	(0.359)	(-1.060)
Investment intensity	0.022**	0.014*	0.011	0.006	0.009*	0.013**	-0.004	0.006	0.007	0.014	0.009	-0.010*	-0.002
	(2.100)	(1.793)	(1.419)	(1.003)	(1.721)	(2.158)	(-0.618)	(0.918)	(0.895)	(1.434)	(1.188)	(-1.904)	(-0.251)
East	-0.029	-0.012	0.016	0.017	-0.003	0.022	-0.020	-0.015	-0.010	0.018	-0.006	0.007	-0.015
	(-1.017)	(-0.571)	(0.749)	(1.207)	(-0.223)	(1.455)	(-1.226)	(-1.033)	(-0.468)	(0.705)	(-0.331)	(0.559)	(-0.948)
Industry FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No of observations	1;442	1;442	1;442	1;442	1;312	1;402	1;402	1;362	1;402	1;442	1;352	1;352	1;402
Log likelihood	-747.39	-545.27	-540.12	-365.13	-282.44	-381.42	-400.54	-367.13	-528.61	-650.65	-430.91	-331.8	-404.89

Robust t-statistics in parentheses; *** p<0.01; ** p<0.05; * p<0.1. Marginal effects (at the mean) are reported.

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