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Firms' eco-innovativeness and its determinants: an empirical cross-country analysis

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Ida D'Attoma, Silvia Pacei (2023). Firms' eco-innovativeness and its determinants: an empirical cross-country analysis. INTERNATIONAL JOURNAL OF BUSINESS ENVIRONMENT, 14(4), 395-416 [10.1504/IJBE.2023.133904].

Availability:

This version is available at: <https://hdl.handle.net/11585/938635> since: 2023-08-11

Published:

DOI: <http://doi.org/10.1504/IJBE.2023.133904>

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The final published version is available online at:

<https://doi.org/10.1504/IJBE.2023.133904>

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Firms eco-innovativeness and its determinants. An empirical cross-country analysis

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Abstract: The paper studies the determinants of different types of eco-innovation in German, Romanian and Portuguese manufacturing sectors over 2012–2014, through an empirical analysis of the Community Innovation Survey. To this end, we consider a measure of eco-innovativeness that counts different types of innovations with environmental benefits that enterprises have undertaken. Due to the count nature of our focal variable and to the large presence of zeros, we estimate a zero-inflated negative binomial model. Drawing upon a consolidated framework of drivers, including ‘technology push’, ‘regulatory push-pull’ and ‘firm-specific’ factors, this work gives an overview of the main eco-innovation drivers and contributes to enlarge the geographical scope of the debate on eco-innovation drivers. Findings highlight how the different regulatory contexts and different levels of competitiveness of the market affect the firms’ eco-innovation behaviour in the three countries and suggest important implications for the design of smart policy mix supporting eco-innovation.

Keywords: eco-innovation; EI drivers; CIS data; ZINB regression.

Reference to this paper should be made as follows: D’Attoma, I. and Pacei, S. (xxxx) ‘Firms eco-innovativeness and its determinants. An empirical cross-country analysis’, *Int. J. Business Environment*, Vol. X, No. Y, pp.xxx–xxx.

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Silvia Pacei is an Associate Professor of Economic Statistics at the Department of Statistical Sciences, University of Bologna. Since 1996, she is a member of the Italian Society of Statistics (SIS) and since 2013 a member of the SIS Standing Coordination Group ‘methods for sample surveys’. Since 2014, she is a member of the Italian Regional Science Association. Her main research interests are innovation and internationalisation effects on firm performance, effect of social transfers on income poverty, and small area estimation of economic indicators.

1 Introduction and motivations

Identifying the determinants of eco-innovativeness is an important task for understanding and removing the obstacles to the diffusion of environmental innovation. Environmental innovation, or eco-innovation (EI), is commonly understood as innovations that are associated with environmental benefits (e.g., Mothe and Nguyen-Thy, 2017; Urbaniec, 2015). Differently from traditional innovation, eco-innovation emphasises “the firms’ mitigation of negative impacts on the natural environment” [Liao and Tsai, (2019), p.317]. Firms implementing eco-innovation tend to be recognised in a positive sense by consumers who are nowadays increasingly aware of environmental topics (Buisse and Verbeke, 2003). Not only to obtain or enhance social legitimacy but also to react or pre-empt their rival’s environmental moves, corporations are inclined to use EI strategies to exploit emerging opportunities (Liao and Tsai, 2019).

Although there has been a significant increase in the knowledge of eco-innovation determinants, some conflicting results are still present in the literature (Bitencourt et al., 2019; Díaz-García et al., 2015). Moreover, over the past decade, several empirical works have analysed the drivers of eco-innovation for single countries and especially among manufacturing firms because of their higher environmental impact, but there is still a lack of country comparisons (Horbach, 2016; Ghisetti et al., 2015, as exceptions).

In light of this, the main purpose of this study was to analyse the main factors enhancing firms focusing on a different number of eco-innovations and providing an understanding of EI determinants in different contexts. We consider data taken by the Community Innovation Survey (CIS) carried out in 2014, as a special section devoted to ‘innovation with environmental benefits’ was included in that survey wave. Eurostat’s release of the new waves¹ no longer contains the module on eco-innovation, so while no longer very recent, it still remains the latest available survey data on the topic.

The CIS has the advantage of a European coverage, thereby allowing country-comparison. We constructed a count measure of eco-innovativeness and then we analysed its determinants by estimating a zero-inflated negative binomial (ZINB) model (Greene, 2009; Hilbe, 2007).

Among the EU countries for which CIS 2014 data were available along with the section devoted to ‘innovation with environmental benefits’, we compared three countries, Germany, Romania and Portugal as the data related to them did not have any missing information as far as innovation and environmental benefits and they displayed a sufficient sample size. The three countries differ in economy, institutional context and eco-innovation performance.

This paper contributes to the existent literature in several ways. First, additional quantitative evidence is provided regarding the EI determinants, that can turn out to be helpful for policy-makers and managers who wish to promote its adoption and diffusion (Ghisetti and Pontoloni, 2015). Second, the literature has been notably reliant on one single country and a few studies have focused on a cross-country analysis. Instead, we considered the cases of three countries, thereby expanding the geographical scope of econometric research on eco-innovation in Europe, which tend to focus mainly on single countries with few exceptions (e.g., Cecere et al., 2020; Horbach, 2016). Third, differently from the large body of literature that used to consider a binary measure of eco-innovativeness, we considered a multidimensional eco-innovation construct that keeps track of all eco-innovations that enterprises simultaneously adopt. Specifically, we consider the number of eco-innovations adopted by the firm as measure of

eco-innovativeness, and then we study the determinants for such focal outcome through a ZINB regression model (Greene, 2009; Hilbe, 2007).

The remainder of this paper is structured as follows. Section 2 describes the relevant literature on the EI determinants and puts forward the research hypotheses. Section 3 presents a brief overview of the peculiarities of the three countries considered, describes data and introduces methodology. Section 4 presents and discusses results. Finally, Section 5 summarises the main results, discusses and concludes.

2 Background literature and hypotheses

2.1 The measure of eco-innovativeness

The empirical literature on the EI determinants typically considers a binary measure of eco-innovation that keeps track to some extent of the specific EI strategy adopted (e.g., Horbach, 2016). As revealed by Triguero et al. (2013), the use of a binary variable to measure eco-innovation activity might cause the loss of valuable information regarding the eco-innovative intensity. Indeed, a composite index has the potential to capture the overall picture of a complex system (Davidescu et al., 2015). It is noteworthy that firms usually do not focus on only one type of eco-innovation, rather they simultaneously adopt more types of eco-innovations. This is also due to the interrelation between various types of green innovations that might motivate firms that have developed R&D and managerial capabilities to simultaneously introduce more than one type of green innovation (Castellacci and Lie, 2017).

Only a few studies have considered a non-binary measure of eco-innovation. Ghisetti et al. (2015) considered the firm's introduction of an eco-innovation as well as the enlargement of its eco-innovation-portfolio by using a count variable. Then, following Ghisetti et al. (2015) and Liao and Tsai (2019) used a count variable, as well. Moreover, Castellacci and Lie (2017) used a principal component analysis (PCA) to reduce eco-innovation variables into a smaller number of factors then used to identify different clusters of eco-innovators.

We consider as a measure of eco-innovativeness, the number of the different types of innovations with environmental benefits (eco-innovation hereafter) adopted by the firm. Summing up the various types of eco-innovation adopted by a firm is possible because in CIS survey, firms are asked to indicate which types of eco-innovation they have adopted among 10 types. Then, we study the determinants of such an eco-innovativeness count measure.

2.2 The potential set of determinants

As a matter of principle, the EI determinants may differ according to the eco-innovation type addressed (Bitencourt et al., 2019), thereby warranting separate investigation (Carillo-Hermosilla et al., 2010). In contrast to this view, the theoretical framework behind our empirical analysis is based on the implicit assumption that eco-innovation adoptions are organisational responses to external changes that require additional investments on the side of enterprises and the alteration of their organisational characteristics (such as processes), in a greater amount than it might be due to adopt

non-eco-innovations. Therefore, in a resources optimisation viewpoint we assume that the adoption of several EI strategies might be driven by the same set of determinants.

We built the present work on the specific strand of literature, relevant to the empirical analysis of the drivers of eco-innovation, which has focused on four main clusters of drivers: technology-push, market-pull, regulatory-push-pull and firm specific factors (Horbach et al., 2012; Rennings, 2000).

'Technology-push factors' are factors related to the development of technological and organisational capabilities. Cooperation (Horbach, 2008, 2016), for example, is recognised as one of these technology-push factors, and similarly, information sources have been recognised as central technology-push factors in spurring the adoption of an eco-innovation (Horbach, 2016; Ghisetti et al., 2015). Many empirical works have identified interorganisational cooperation as a relevant EI determinant [for a review see Pereira et al. (2020)]. One of the main reason is that cooperation enables firms to overcome possible limitations to eco-innovation due to resource constraints in terms of knowledge, technologies and skills. EI are in fact typically more complex and demanding than other innovations (Castellacci and Lie, 2017). Those resources can be developed thanks to the involvement of external partners. This aspect is obviously more important for small firms than for large companies (Triguero et al., 2016).

Moreover, high costs and risks connected to eco-innovation may discourage firms from stepping into eco-innovation activities in practice. Cooperation allows to reduce costs connected with those environmental practices, as it can produce economies of scale (Fabrizi et al., 2018), and it allows to reduce uncertainty and share the risks related to eco-innovations (Triguero et al., 2016).

In Cainelli et al. (2015) and Ghisetti et al. (2015) for example, argued that the wider the array of knowledge sources or partners on which an enterprise relies, the greater the likelihood that it designs an eco-innovation strategy. Finally, cooperation may affect the introduction of eco-innovation of different types, such as product eco-innovation (Dangelico, 2017), process eco-innovation or management eco-innovation (He et al., 2018), as well as it can involve different partners, not only other firms, but also suppliers, clients, university (Bossle et al., 2016).

With these considerations in mind, we put forward the following hypothesis:

H1 The higher the cooperation intensity, the greater the enterprise eco-innovativeness.

Internal and external R&D efforts are other factors that encourage firms to place eco-innovation activities as well (Ghisetti and Pontoloni, 2015; Cainelli et al., 2015; Marin and Zanfei, 2019). Horbach (2008) found that firms improving their technological capabilities through R&D are also more likely to be updated on new environmental possibilities. Moreover, innovation intensity is acknowledged to have a positive effect on the scope of environmental benefits identified by the eco-innovation strategies (Liao and Tsai, 2019).

Technological capabilities proxied by qualified employees contributes to develop new products and processes (Cainelli et al., 2015; Horbach, 2008; Horbach et al., 2012) but also play an important role in the realisation of eco-innovation (Horbach, 2016; Bitencourt et al., 2019), as a result of the availability of greater technical knowledge within a company that moderates its vulnerability in facing the demands of new environmental regulations (Canon de Francia et al., 2007).

As far as 'market-pull factors' are concerned, among other factors, i.e., market turbulence (Hofstra and Huisingsh, 2014), there is a general consensus in the empirical

literature on the fact that the expectation of a future demand created by eco-conscious customers is likely to give rise to investments in environmental innovations (Horbach, 2008, 2016; Wagner, 2008; Triguero et al., 2013; Liao and Tsai, 2019), having enterprises realised that green consumers can be a profitable segment (Hojnik, 2017). Eco-conscious consumers' demand is a strong driver of eco-innovativeness especially in those product markets which are close to the final consumers (Doran and Ryan, 2012). However, a market pull effect is more likely in countries with high environmental awareness, and less likely in countries with low environmental awareness and low willingness to pay more for eco-products. Unfortunately, CIS data do not include any questions nor a proxy that can enable a deep analysis and test hypotheses on such a potential determinant.

As far as 'regulatory-push-pull factors' are concerned, many studies have stressed that environmental regulation is the most important stimulus that leads firms to eco-innovate (Ghisetti and Rennings, 2014; Del Rio et al., 2017; Horbach, 2016; Liao and Tsai, 2019). Environmental regulation refers to the regulations enacted by governments to protect or improve the environment to promote sustainability (Liao and Tsai, 2019). The effect of regulation on eco-innovation has been developed around the debate on the Porter hypothesis, according to which environmental regulations lead to a win-win situation where simultaneously pollution is reduced and productivity or the product-value for the end-user increased (Porter, 1991; Porter and van der Linde, 1995). The key role of regulation as the main trigger factor of eco-innovation stems from the double externality problem, that is a peculiarity of eco-innovation (Porter and van der Linde, 1995; Rennings, 2000; Horbach, 2008). The double externality problem regards production of the common spillovers of innovations in general as well as the creation of less environmental external costs (Rennings, 2000). This signifies that the whole society benefits from an eco-innovation, while a single enterprise bears all the costs (Beise and Rennings, 2005), thus increasing the importance of the regulatory framework.

On the one hand environmental regulation imposes additional production costs that can lead to a reduction of firm's competitiveness. On the other hand, environmental regulation may imply a savings of materials and energy, that can compensate the additional production costs so that firm's competitiveness increases (Horbach, 2020). Moreover, environmental regulation may lead to the adoption of new technologies that bring first-mover advantages to the firm and its related suppliers in the value chain. The final effect obviously depends on different conditions, such as the type of policy instruments and the context in which they are applied (Leitner et al., 2010). However, as stated by Horbach (2020) the main objective of an environmental policy is to improve firm's environmental performance, other positive effects on firm's competitiveness are welcome side effects.

Despite the importance of environmental regulation, due to the lack of adequate data, empirical analysis on its effect is rarely present in existing studies on eco-innovation. Following Ghisetti et al. (2015), in this work we consider a proxy for the environmental regulation and we put forward the following hypothesis:

H2 Environmental regulations positively affect the eco-innovativeness.

As concerns the public support to firms' innovation in general, there is not a consensus on its impact on eco-innovation. Kunapatarawong and Martínez-Ros (2016) found a positive impact and similar results have been found in several studies (Del Rio et al., 2015; Horbach et al., 2012; De Marchi, 2012). Nevertheless, public innovation policies do not seem to have an effect on eco-innovation in other studies (e.g., Horbach et al., 2012; Triguero et al., 2013). Owing to the high cost and high risk of eco-innovation, enterprises tend to be reluctant to eco-innovate and governments are conducive to promote it (Ma et al., 2019) with the aim to improve eco-innovation rates. It is acknowledged that European countries differ with respect to investments in innovation inputs and outputs (European Commission, 2014) and, as highlighted by Grabowsky and Staszewska-Bystrova (2020), enterprises from different countries may react in different ways to public innovation support. Such a difference may depend upon being a post-transition economy, where the propensity to buy machinery and equipment is higher and the propensity to invest in R&D and innovation output is lower (Szczygielski and Grabowsky, 2014), or a developed one, with innovation-based growth strategies (Acemoglu et al., 2006). Besides the contrasting results, empirical literature has generally converged on a positive effect of public support, that holds especially true for eastern European countries. In fact, due to the before mentioned high costs for the transition to cleaner production, the eastern European countries are unduly dependent on subsidies (Horbach, 2016). Based on the preceding considerations and embracing the distinction between post-transition and developed economies, we put forward the following hypotheses:

H3 Public funding affects the eco-innovativeness in countries with a post-transition economy.

Besides the four main clusters of drivers, we envisaged the forms of innovation protection as an important trigger factor of eco-innovation still to be explored. In light of the double externality problem, even when a firm successfully reaches the market with an eco-innovation, the profit appropriation could still result difficult especially in case the eco-innovation is accessible to potential imitators (Hojnik, 2017; Beise and Rennings, 2005). As reported in Pereira and Vence (2012), the double externality problem represents a market failure that is due to the relative simplicity to reproduce knowledge in contrast with the obstacles to its creation, thereby generating a disincentive to invest in eco-innovation. Moreover, as acknowledged in Golombek et al. (2020), the literature on environmental R&D tends to denote the appropriability problem as larger for environmental R&D than for non-environmental ones. As reported in Montgomery and Smith (2007, p.31), especially in the setting of innovation in climate technology, "problems of appropriability are likely to appear" and are "exacerbated by the possibly long time and indirect connection between scientific achievement and the actual production of low-carbon energy." In addition to this, as reported in Seo et al. (2016), appropriability is especially crucial for small and medium-sized enterprises (namely, the focus of our empirical analysis) for achieving long-term sustainable survival due to the lack of complementary competencies. Therefore, we put forward the following hypothesis:

H4 The higher the number of forms of protection adopted by an enterprise the higher its eco-innovativeness.

3 Data and methodology

3.1 Data and country setting

This study was based on firm-level data from the 2014 European Union CIS of Germany, Romania and Portugal in the period 2012–2014. The sample covers 3,250, 4,325 and 3,810 manufacturing firms with more than ten employees across different industries for Germany, Romania and Portugal, respectively.

The consideration of three different settings was intended to increase the robustness of the results as it allows us to figure out more clearly the determinants of eco-innovation net of the contextual differences. Germany is an eco-innovation leader, Romania is catching up with eco-innovator countries but experiences different level of firms' innovativeness and different regulatory frameworks, and Portugal ranks between these two countries. In particular, according to the European innovation scoreboard, Germany was a strong innovator in 2013, Romania was the less innovative one, whereas Portugal is close to the EU average.

Germany represents the largest manufacturing economy in Europe, performs particularly well in terms of EI activities and has developed an advanced regulation in this context (Tudor et al., 2017). It has adopted several policy measures to address circular economy and eco-innovations and is characterised by an avant-garde waste infrastructure and high recycling rates (Bahn-Walkowiak and Wilts, 2016; O'Brien, 2018). However, according to the Eco-innovation Observatory of the European Commission (O'Brien, 2018), large differences were observed between small and large enterprises with respect to circular and green economy. This evidence highlights that small sized enterprises encounter barriers, which prevents them from engaging in eco-innovation activities.

Romania represents a post-transition economy and belongs to the group of countries with the least developed economy in EU at the moment, even though it experienced some of the highest growth rates in the EU (for example its GDP growth rate was 4.2% in 2019). Romanian firms aim to be competitive through a low-cost production model, so they consider the costs of using resources efficiently as a barrier. Romania, despite some initiatives, has not developed an integrated strategy for circular economy and eco-innovations. This lack in the regulatory framework is perceived by Romanian companies as a big obstacle to investing in resources efficiency measures (Roman, 2018).

Portugal is mainly a service-based economy, even though in recent years Portugal has increased its role in some European manufacturing sectors (the automobile sector, biotechnologies and IT). Some improvements in EI certifications and the emergence of eco-innovative sectors placed the Portugal's performance slightly above the EU average according to the Eco Innovation Observatory (Costa and Lorena, 2016). Despite some resource efficiency policies introduced from 2013 to 2015, a solid policy framework for eco-innovation and circular economy is still missing (Costa and Lorena, 2016; Lorena, 2018).

Moreover, the intense interplay between the three countries considered warrants analysing EI determinants they might share. Germany is one of the main investing countries in Romania (United Nations, 2020). The main sector attracting FDI in Romania is manufacturing and one of the main advantages for attracting FDI is that in Romania the cost of labour is among the lowest in EU and the workforce is qualified. Germany also represents one of the most important trading partners for Portugal.

3.2 *The outcome variable*

The CIS defines an eco-innovation as “a new or significantly improved product (good or service), process, organisational method or marketing method that creates environmental benefits compared to alternatives.” The definition is not only confined to the technological sphere but it also encompasses organisational and market aspects. Because only firms that innovate can adopt an eco-innovation strategy, our analysis focuses on innovative firms only.

The eco-innovativeness measure we consider is the number of eco-innovations adopted by a firm, that ranges from 0 (no eco-innovation strategy was in place) through 10 (all environmental strategies were implemented).²

3.3 *The explanatory variables*

For what concerns explanatory variables, we followed the before mentioned body of literature that has focused on four main clusters of drivers. As *technology-push* factors we considered the *degree of cooperation* defined as the number of types of innovation cooperation partners with which the enterprise undertakes an active cooperation, the *innovation intensity* described by the ratio of the total expenditure on innovation and *technological capabilities* proxied by qualified employees. As *regulatory push-pull* factors, we took into account whether the enterprise has received public support for its innovation activity in general (and not targeted at environmental innovation).³ Then, because CIS data did not allow us to directly consider the role of environmental regulations, as a proxy of environmental regulation we adopted the logarithm of CO₂ air emission intensities expressed as ratios relating carbon dioxide emissions to value added by manufacturing industries (classified by NACE Rev. 2) in each country considered.⁴ As *firm-specific* factors we considered firm size, industry⁵, whether the firm belongs to a group, whether the head office of the group is located abroad, the exporting behaviour, the employee growth rate and the turnover growth rate, all considered as important EI drivers (e.g., Liao and Tsai, 2019; Dangelico, 2017; Chiavesio et al., 2015; Horbach, 2016).

Finally, following D'Attoma et al. (2021), we built a variable that approximates the appropriability condition constructed by summing up a set of six dummies denoting each a form of protection adopted by the firm and then rescaling it by dividing the value obtained by 6.

3.4 *Methodology*

Unlike what has been done so far in the literature we measured the eco-innovation intensity through a count measure and then we accordingly analysed its determinants. We observed that the number of eco-innovations is 0 for a non-negligible number of innovative firms in all three countries. The count nature of such outcome variable and the large presence of zeros, lead us to use the ZINB regression model (Greene, 2009; Hilbe, 2007). In fact, in our case, the negative binomial model may not accurately assign probability to the outcome $Y = 0$. The zero count $Y = 0$ occurs because the enterprise would never eco-innovate, regardless of the characteristics that appear in the model. Otherwise, $Y = 0$ happens to be the number of eco-innovations adopted in the survey period. But, at some other time, the same enterprise might choose $Y = j > 0$.

The ZINB model is a ‘two-part’ count data model, as it considers two data generation processes simultaneously influencing the outcome. For each observation i the first process, represented by d_i , gives zero counts ($Y_i = 0$) with probability π_i (when $d_i = 0$), and the second process, with the complementary probability $1 - \pi_i$ (when $d_i = 1$) provides counts ($Y_i \geq 0$) according to a negative binomial with mean λ_i . Therefore, the second process may generate zero counts as well.

The model can be represented as follows:

- $Y_i = 0$ with probability π_i
- $Y_i \sim NB(\lambda_i)$ with probability $1 - \pi_i$.

So that, the probabilities connected to the two possible outcomes are:

$$Prob[Y_i = 0] = \pi_i + (1 - \pi_i) R_i(0) \quad (1a)$$

$$Prob[Y_i = j > 0] = (1 - \pi_i) R_i(j) \quad (1b)$$

where

- $R_i(j)$ = the negative binomial probability = $\Gamma(\theta + y_i) / [y_i! \Gamma(\theta)] u_i^\theta [1 - u_i]^{y_i}$
- $\theta = 1/\alpha$, where α is the overdispersion parameter
- $u_i = \theta / (\theta + \lambda_i)$
- $\lambda_i = \exp(\beta' x_i)$.

With x_i as the vector of covariates and β the vector of related coefficients.

For probability π_i we use a logistic probability model:

$$\pi_i \sim \text{Logistics}(\delta' w_i) \quad (2)$$

and we consider the same auxiliary variables used in the NB model ($w_i = x_i$).

The joint density can be written as follows:

$$P(P(y_i, d_i | x_i)) = (1 - d_i) \pi_i + d_i (1 - \pi_i) R_i(y) \quad (3)$$

while the conditional mean function is $(1 - \pi_i) \lambda_i$.

We use the incidence rate ratio (IRR) to evaluate the effect of auxiliary variables on the dependent variable in the NB model (count equation) and the odds ratio (OR) to evaluate the effect of auxiliary variables on the dependent variable in the logit model (inflated equation).

4 Results and robustness check

4.1 Results

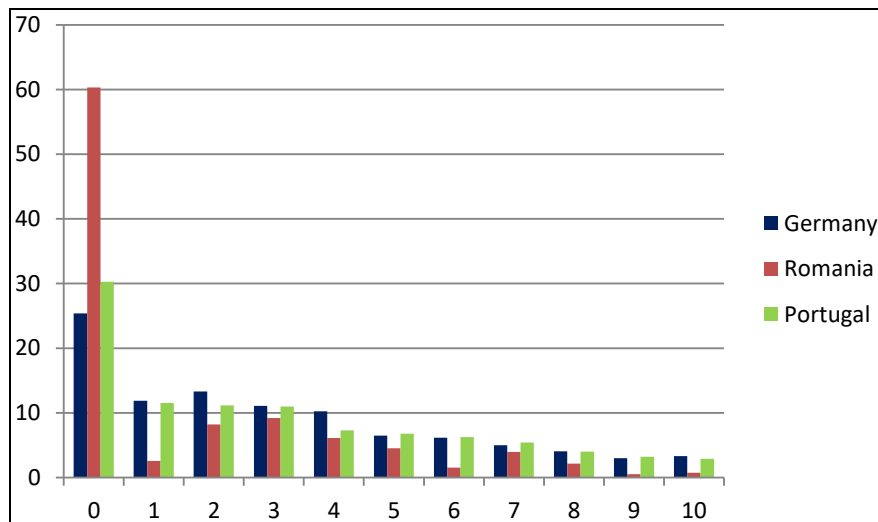
Our response variable counts the number of eco-innovations adopted by a firm. Thus, the Cronbach's (1951) alpha coefficient is computed to evaluate the reliability of this type of

construct by determining its internal consistency. The Cronbach's alpha is 0.89, 0.88 and 0.85 for Germany, Romania and Portugal, respectively, thus confirming that the indicators are measuring the same underlying construct and it makes sense to calculate the sum.

Germany shows, as expected, the greatest resort to eco-innovation among the three countries considered. 12% of firms in the German data reported only one type of eco-innovation, whereas about 63% reported two or more types, as many as 3.3% reported all 10 and about 25% reported zero eco-innovations. Similar percentages are observed for Portugal: 11.6% of firms adopted only one type of eco-innovation, 58% adopted two or more types, 2.9% adopted all 10 types and about 30% innovated without environmental benefits. Instead, the presence of zeros is higher in the case of Romania, where about 60% of manufacturing firms reported zero eco-innovations, about 3% only one type, about 37% reported two or more types and only about 1% reported all 10.

Figure 1 shows the percentage distribution of the three countries' firms by eco-innovations.

Figure 1 Percentage distribution of firms by number of eco-innovations in Germany, Romania and Portugal (see online version for colours)



Note: Percentages are calculated using sampling weights.

Source: Own elaboration of the CIS 2014 data

Tables 1 and 2 report results obtained respectively from the 'count equation' and the 'inflate equation' of the ZINB model, for Germany, Romania and Portugal. The Vuong statistic is 7.4 for Germany, 7.5 for Romania and 9.1 for Portugal. In all cases it favours the ZINB model with respect to the standard negative binomial model.

Table 1 The determinants of eco-innovation in Germany, Romania and Portugal: parameter estimates in the ZINB model – count model

Covariate	Germany		Romania		Portugal	
	IRR (SE)	z	IRR (SE)	z	IRR (SE)	z
<i>Count equation</i>						
Degree of cooperation	1.4633*** (0.1677)	3.32	2.2637*** (0.6908)	2.68	1.3990*** (0.1434)	3.28
Innovation intensity	1.5138* (0.3305)	1.90	2.4024* (1.2027)	1.75	1.0076 (0.0161)	0.47
Qualified employees	0.9989 (0.0030)	-0.36	1.0110 (0.0083)	1.33	0.9958 (0.0031)	-1.34
Qualified employees (squared)	0.9999 (0.0000)	-0.04	0.9998* (0.0000)	-1.82	1.0001* (0.0000)	1.78
Public funding	0.9449 (0.0468)	-1.14	0.7932 (0.1156)	-1.59	1.0352 (0.0416)	0.86
Environmental regulation (ln)	1.0254* (0.0135)	1.91	1.0155 (0.0294)	0.53	0.9806* (0.0108)	-1.76
Export	0.9933 (0.0490)	-0.13	1.4955*** (0.1815)	3.31	1.058 (0.0593)	1.01
Group membership	0.9326 (0.0683)	-0.95	0.8629 (0.1016)	-1.25	1.0048 (0.0631)	0.08
Foreign multinational	0.9794 (0.0690)	-0.29	1.3253 (0.2514)	1.48	0.9658 (0.0636)	-0.53
50–249 employees	1.0640 (0.0483)	1.37	0.8186 (0.1036)	-1.58	1.0338 (0.0427)	0.81
250–499 employees	1.2473*** (0.0901)	3.06	1.0148 (0.1517)	0.10	1.1945*** [#] (0.0844)	2.51
500 and more employees	1.3117*** (0.0982)	3.62	1.1918 (0.1915)	1.09		
High-tech sector	0.7622*** (0.0584)	-3.54	0.6488* (0.1532)	-1.83	0.5947*** (0.0714)	-4.32
Medium-tech sector	0.9023** (0.0386)	-2.40	1.2533** (0.1329)	2.13	0.9262** (0.0341)	-2.08
Employees growth rate	1.0522 (0.0565)	0.95	0.8571 (0.1002)	-1.32	1.0152 (0.0273)	0.56
Turnover growth rate	1.0002 (0.0005)	0.45	0.9972 (0.0050)	-0.53	0.9974 (0.0098)	-0.26
Level of protection	1.5430*** (0.1335)	5.01	0.9617 (0.2884)	-0.13	1.0637 (0.1630)	0.40

Notes: [#]250 and more employees in the case of Portugal.

***1% significance, **5% significance and *10% significance.

Source: Own elaboration of the CIS 2014 data

Table 2 The determinants of eco-innovation in Germany, Romania and Portugal: parameter estimates in the ZINB model – inflate model

<i>Covariate</i>	<i>Germany</i>		<i>Romania</i>		<i>Portugal</i>	
	<i>OR (SE)</i>	<i>p-value</i>	<i>OR (SE)</i>	<i>p-value</i>	<i>OR (SE)</i>	<i>p-value</i>
<i>Inflation equation</i>						
Degree of cooperation	0.4416 (0.3236)	0.2648	0.3707 (0.4287)	0.3909	0.2849** (0.1570)	0.0228
Innovation intensity	1.3083 (0.1.0363)	0.7344	0.9991 (0.1.3061)	0.9995	0.1995* (0.1785)	0.0716
Qualified employees	0.9900 (0.0124)	0.4259	1.0272 (0.0217)	0.2045	0.9783** (0.0103)	0.0384
Qualified employees (squared)	1.0002 (0.0001)	0.1864	0.9996 (0.0002)	0.1895	1.0004*** (0.0001)	0.0008
Public funding	0.9646 (0.2364)	0.8832	0.3409** (0.1606)	0.0224	0.7248** (0.1128)	0.0387
Environmental regulation (ln)	0.7840** (0.0751)	0.0111	0.8284** (0.0644)	0.0155	0.9326 (0.0407)	0.1110
Export	1.0537 (0.2020)	0.7848	1.0712 (0.2899)	0.7993	0.9611 (0.1729)	0.8258
Group membership	0.4497 (0.2600)	0.1669	0.7234 (0.2478)	0.3447	0.7451 (0.1946)	0.2602
Foreign multinational	0.4518 (0.2653)	0.1762	1.0679 (0.6175)	0.9095	0.9755 (0.2895)	0.9335
50–249 employees	0.4881*** (0.0982)	0.0004	0.5383** (0.1583)	0.0353	0.9598 (0.1406)	0.7800
250–499 employees	0.3973** (0.1820)	0.0439	0.3483*** (0.1351)	0.0066	0.6985# (0.2326)	0.2814
500 and more employees	0.2838** (0.1650)	0.0303	0.3402** (0.1483)	0.0134		
High-tech sector	1.1855 (0.3564)	0.5713	0.7332 (0.4426)	0.6073	0.7544 (0.3707)	0.5665
Medium-tech sector	0.6580** (0.1292)	0.0331	0.7905 (0.2129)	0.3829	0.8997 (0.1179)	0.4201
Employees growth rate	0.8461 (0.2330)	0.5442	1.1254 (0.2890)	0.6453	1.0678 (0.0999)	0.4832
Turnover growth rate	0.9989 (0.0068)	0.8723	0.9777 (0.0240)	0.3592	1.0641* (0.0346)	0.0563
Level of protection	0.1915*** (0.1010)	0.0017	0.0194*** (0.0250)	0.0022	0.6979 (0.4358)	0.5646

Notes: #250 and more employees in the case of Portugal.

***1% significance, **5% significance and *10% significance.

Source: Own elaboration of the CIS 2014 data

Starting with Germany, the following variables were significant at least at 10% level in the count equation: degree of cooperation, innovation intensity, environmental regulation, size (medium and large), high-tech sector, medium-tech sector and level of protection.

As the degree of cooperation of enterprises increased of one unit, the number of eco-innovations had a 46.3% increase, Hypothesis H1 is then supported. This result might be due to the fact that eco-innovations are more complex and demanding than other types of innovation, thus requiring more resources picked up from external partners and sources of knowledge. In line with literature, innovation intensity was also found to have a positive effect on eco-innovation. Environmental regulation was found to be a significant stimulus to eco-innovation at 10% level: if the CO₂ air emissions intensity increased by 1% then the number of eco-innovations increase by 2.5%. Hence, support for Hypothesis H2 was found. We may argue that, firms in those sectors characterised by higher CO₂ emission intensity are pushed by the environmental regulation to introduce more eco-innovation activities.

The number of eco-innovations adopted by a firm increased as size classes increased (the smallest class dummy '49 or less' employees was excluded from the model). Enterprises with 250–499 employees had about a 25% increase in the number of eco-innovations compared to enterprises who had less than 50 employees. The increase is even higher in the case of enterprises with 500 and more employees (31%). Conversely, enterprises who belong to the high-tech sectors and to the medium-tech sector had respectively a 23.8 and a 9.8% decrease in the number of eco-innovations compared to the enterprises in the low-tech sector (reference category). Furthermore, another important determinant for the number of eco-innovation is the level of protection: as the degree of protection increased by one unit, the number of eco-innovations had a 54.3% increase, Hypothesis H4 is then supported. As it is well known in Germany the number of firms that apply for patents, even with reference to the environment, is particularly high (OECD, 2009), and this result on the relationship between level of protection and eco-innovation highlights Germany as an innovative economy where firms are engaged in intense competition and a sheer number of ideas come up.

The inflation equation predicts the absolute zero group. The risk of being in that group was found to significantly reduce when CO₂ air emission intensity, the size and the level of protection increase. In other words, as expected, small firms, firms with a low level of protection and firms belonging to sectors with less CO₂ air emission intensity tend not to resort to eco-innovation. In particular, the risk of being in the absolute zero group decreased by 0.22% if the CO₂ air emission intensity increased by 1%; it progressively decreased by 51, 60 and 72% as the size class increased, compared to smallest firms; it decreased by 81% if the level of protection index increased by 1. Moreover, it decreased by 34% among firms belonging to medium tech sectors with respect to firms belonging to low tech sectors. To put things differently, firms in medium tech sectors tend to resort more than firms in low tech sectors to eco-innovation even though they tend to carry out a lower number of eco-innovation activities (see results from the count equation).

As far as Romania is concerned, the determinants relevant for eco-innovation were different from those discussed for Germany, except for the cooperation intensity and innovation intensity. Similarly to Germany, a firm that experienced a one unit change in the cooperation intensity is expected to have an increase of 126% in the number of eco-innovations, Hypothesis H1 is then supported. Moreover, an enterprise that experienced a one unit change in the innovation intensity had a 140% increase in the number of eco-innovations. Differently from Germany, enterprises who belong to the

medium-tech sector experienced a 25% increase in the number of eco-innovations compared to enterprises in the low-tech sector.

In addition, differently from Germany, the following firm's characteristics were significant at least at 10% level: qualified employees (squared) and export. The number of eco-innovations is 50% higher for exporter firms with respect to non-exporter ones and the number of eco-innovations decreases, nonlinearly, as the percentage of qualified employees increases. This suggests that firms carrying out tasks for which less qualified workers are necessary are more involved in eco-innovation activities.

On the other hand, the environmental regulation as well as the level of protection, did not affect the Romanian firms' number of eco-innovations. Nevertheless, they both negatively affected the probability of belonging to the absolute 0 group in the inflate equation, together with the size and the fact of receiving public support to innovation. In fact, differently from Germany the risk of being in the absolute zero group decreased by 66% if the enterprises received public support to innovation, therefore Hypothesis H3 is supported.

While results obtained for Germany and Romania showed a few, even though important differences, those obtained for Portugal showed some unexpected differences from the previous two analysed countries. In the case of the count equation, Portugal shared with Germany and Romania only the following significant determinants: the degree of cooperation (H1 supported), with the same positive sign and, only with Germany, the size and the level of technology sector (medium and high), with the same sign.

Then, the qualified employees (squared) is significant at 10% level, as for Romania, but with a positive sign, and the CO₂ air emission intensity is significant at 10% level, as for Germany, but with a positive sign. Therefore, while in the case of Romania the number of eco-innovations decreased in a nonlinear way as the percentage of high educated personnel increase, the contrary happened for Portugal. This result can be related to the sector of activity. In fact, we noticed in CIS data that there are some sectors in Romania where firms carried out few eco-innovation activities on average but have a high percentage of qualified workers on average (for example sectors 'printing and reproduction of recorded media' and 'manufacture of basic pharmaceutical products and pharmaceutical preparations'), while in other sectors, as 'manufacture of fabricated metal products, except machinery and equipment', firms with more eco-innovation employ lower percentages of qualified workers on average. The contrary happened in Portugal, where sectors with higher levels of both eco-innovation and qualified workers (as for example 'manufacture of basic pharmaceutical products and pharmaceutical preparations') are opposed to sectors with lower levels of both eco-innovation and qualified workers ('manufacture of other transport equipment' and 'other manufacturing').

Regarding results obtained for the environmental regulations, we noticed that in Germany, in those sectors where the CO₂ air emission intensity was higher, the number of eco-innovations were higher as well, while the opposite occurred in Portugal, where Hypothesis H2 is not supported. In this regard, we noticed in CIS data that in Portugal there are some sectors where, despite the lower level of CO₂ emission, firms adopt on average a high number of eco-innovation activities (more than 5). They are, for example, 'printing and reproduction of recorded media', 'manufacture of motor vehicles, trailers and semi-trailers' and 'manufacture of furniture'. This may be explained by a greater attention to the environment in those sectors, and by the fact that Portuguese companies

have not just waited for the governments to decree regulations, but have voluntarily adopted codes of conduct or participated in sectorial agreements for the implementation of good environmental practices (da Silva et al., 2014).

Results obtained for the inflation equation highlight that, in Portugal, receiving public funding reduced the probability of being in the absolute zero group (like in Romania). Hence, Hypothesis H3, that restricts significant effects of public funding to countries with a post-transition economy, is not supported by this result. This result is in line with Leitao et al. (2019), who found that public policies have a positive influence on eco-innovation, while it disagrees with Scarpellini et al. (2018), who found that public incentives would reduce the risk associated with investing in eco-innovation project for Portugal. Moreover, other determinants, significantly affect the probability of being in the absolute zero group that were found not relevant for the other two countries. Such determinants are some 'technology-push factors', as the degree of cooperation, the innovation intensity level and the percentage of qualified employees and a firm specific factor that is the turnover growth rate.

Finally, the level of protection was not found to be a relevant determinant for Portugal, neither in the count equation nor in the zero inflated equation. We notice in our data that the level of protection indicator is much lower on average in Portugal than in Germany (0.17 in Germany, 0.06 in Romania and 0.05 in Portugal) and also much less variable. This explains its non-significance as a determinant in the model.

4.2 Robustness check

As a robustness analysis we consider an alternative indicator of eco-innovativeness since the count measure used may suffer from the correlation between the different environmental benefits associated to the innovations adopted. Therefore, we consider a composite index constructed by using a PCA-based strategy that allows us to solve the problem of correlation but, on the other hand, leads to a loss of information with respect to the use of the original observed variables. We used the fractional probit (FP) model (Papke and Wooldridge, 1996) to study the dependence of such an index on possible determinants.

We observe an overall consistency between the determinants resulting significant, with a few exceptions. In particular, as regard to Germany, according to the FP model the turnover growth rate is found to be an important determinant of the eco-innovativeness index, with a positive sign, while in the ZINB model its effect does not arise. As regard to Romania, from the zero equation of the ZINB model arises a positive impact of public funding on the use of eco-innovations, which remains hidden the FP model. Finally, as regard to Portugal, the percentage of qualified employees and the fact of belonging to the medium-tech sector do not arise as relevant determinants in the FP model, while they arise as significant determinants in the ZINB model.⁶

5 Discussion and conclusions

5.1 Contribution to theory and practice

The aim of this work was to study the main factors enhancing firms focusing on a different number of eco-innovations in Germany, Romania and Portugal. The main

contribution to the literature of our study is represented by the rich analysis of potential EI determinants in three different countries, that provide an understanding in different contexts. In particular, the study helps fill the lack of comparative empirical studies in this area, where very commonly there are single-country studies. In addition, our work considers a not common measure of eco-innovation, which allows to recover information about the intensity of eco-innovation that would be lost through the use of a binary measure, namely the most commonly used measure in the empirical literature on the determinants of eco-innovation. The results highlight how the different regulatory contexts and different levels of competitiveness of the market affect the firms' eco-innovation behaviour in the three countries and suggest important implications for the design of smart policy mix supporting eco-innovation. Table 3 summarises empirical support to the hypotheses.

Table 3 Summary of empirical support to hypotheses in the main analysis

<i>Hypothesis</i>	<i>Main analysis (ZINB model)</i>		
	<i>Germany</i>	<i>Romania</i>	<i>Portugal</i>
H1 The higher the cooperation intensity, the greater the enterprise eco-innovativeness	Supported (count)	Supported (count)	Supported (count and inflate)
H2 Existing or expected environmental regulations positively affect the eco-innovativeness	Supported (count and inflate)	Supported (inflate)	Not supported (count and inflate)
H3 Public funding positively affects the eco-innovativeness in post transition economies (but not in developed economies)	Supported (count and inflate)	Supported (inflate)	Supported (count) not supported (inflate)
H4 The higher the number of forms of protection adopted by an enterprise, the higher its eco-innovativeness	Supported (count)	Supported (count)	Supported (count and inflate)

Source: Own elaboration of the CIS 2014 data

Starting with the environmental regulations, they assume greater importance for Germany than for Romania where it affects the fact of adopting eco-innovation but not the number of eco-innovation activities. Furthermore, in Portugal, environmental regulations do not seem to affect EI firms behaviour, as firms in some sectors with lower level of CO₂ emissions tend to innovate a little more than the others. This highlights the spontaneous resort to eco-innovation by firms/sectors which are more sensitive to environmental issues. Furthermore, in Romania and Portugal an important role on the decision to eco-innovate is assumed by the fact of receiving public funding.

Then, high levels of eco-innovation in Romania seem, in the period considered, a prerogative of firms which are more open to the external, such as those which cooperate and export, while in Portugal they seem a prerogative of cooperating firms, large firms and firms belonging to specific low-tech sectors.

5.2 Policy and managerial implications

Our results highlight the need, in Romania and Portugal, for eco-innovation to be further promoted and incentivised by policymakers, by mitigating the obstacles to

eco-innovation and resorting to different environmental and technology policies. Regulation initiatives are confirmed to be crucial determinants for the implementation of eco-innovations.

With regards to the three countries considered, we found that, smaller firms are less prone to adopt eco-innovations. This represents one of the few limits that emerges also for Germany. This could be due to the lack of knowledge and human and material resources that characterise small sized enterprises. Therefore, small enterprises should be incentivised more than larger ones to develop eco-innovation activities, by helping them in acquiring the necessary knowledge and skills.

The intellectual property regime assumes a relevant role in stimulating firms to carry out eco-innovations. From our study it emerged that the level of protection assumed a relevant role for Germany in both the examined decisions, namely the decision to eco-innovate and the decision on the number of eco-innovation strategies to adopt, while for Romania it affects only the decision to eco-innovate and for Portugal none of the two. Intellectual property rights are recognised to play an important role for the transition to a green economy, therefore their strong relationship with eco-innovation was expected. However, in Romania and Portugal the level of protection adopted by firms results particularly lower than in Germany and, above all in Portugal, it is not able to explain the adoption of eco-innovations. This result highlights the importance of adopting strategies to facilitate the access to licensing of eco-technologies, improve access to green patents applications and foster the diffusion of eco-patent commons. In this regard, the access to knowledge, technologies and skills could be also fostered by specific policies that lead firms to cooperate with each other or with other partners for eco-innovation development.

On the managerial side, this study is important for business decision makers since, for instance, it emphasises cooperation as an important driver for those firms who want to adopt a sustainability perspective. Indeed, while not analysing the effects of adopting eco-innovation but only its determinants, it is known in the literature that it has, in turn, a bearing on firm performance (e.g., Barriga Medina et al., 2022; Hizarci-Payne et al., 2021). To this aim, firms should dedicate much effort to build competencies and establish links with relevant actors in order to take advantage of knowledge developed by cooperation partners in the field of environmental innovation. Not only the role of managers, but also that of policy-makers is relevant to create appropriate environments for cooperation and boost eco-innovation intensity within the firm. In general, sharing information on the adoption of multiple sustainable strategies may help firms mitigate the high costs related to the introduction of eco-innovation practices (e.g., Boutry and Nadel, 2021).

5.3 Limitation and future research directions

This study has some limitations. The cross-sectional nature of our sample did not enable us to draw valid conclusions regarding any association or possible causality. The anonymised CIS data, as often happens for sample surveys on firm's innovation, does not allow matching of enterprises across different waves.

Not all the necessary variables to draw more solid conclusions about the determinant factors of eco-innovation are available in CIS 2014. For instance, the data at hand did not include precise information on eco-innovative expenditure that might influence the

adoption of different eco-innovations. Moreover, there is the lack of information about market-pull factors as a potential cluster of drivers.

Results on environmental regulations represent a call for further research on how environmental policies influence the degree of eco-innovation and whether such an influence is related to the kind of policy and to the political economy of the specific country, thereby bringing to light the need of further information on the decision to adopt EI.

Moreover, further research might use a different set of data which include information also on tangible and intangible investments, or eco-patents. These data may provide more specific information on the EI introduction, thus allowing to go further into the environmental profile of innovative firms.

Lastly, a weakness is represented by the inadequate timeliness of the CIS 2014 wave used in our empirical application. However, such a weakness is common to all empirical studies that make use of CIS data. Future research might use new and, hopefully, more recent set of data.

5.4 *Concluding remarks*

In conclusion, it can be said that the practical contribution of this study is to consolidate a comprehensive picture of determinants of eco-innovation for European enterprises, such as SMEs in transition and non-transition countries. This study provides important insights and challenges to academics, policy makers and managers to improve the diffusion of eco-innovative practices by leveraging particular aspects of business life including, for example, cooperation in innovation.

Disclaimer

The anonymous data of the CIS 2014 used in the analysis of this paper was provided by EUROSTAT. All results and conclusions are given by the authors and represent their opinion and not those of EUROSTAT, the European Commission or any of the national authorities whose data have been used. The responsibility for all conclusions drawn from the data lies entirely with the authors.

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Notes

- 1 <https://ec.europa.eu/eurostat/web/microdata/community-innovation-survey>.
- 2 CIS 2014 includes ten types of eco-innovations: material use reduction; energy saving; air, water, noise or soil pollution reduction within enterprise; substitution of polluting and hazardous materials; substitution of fossil energy with renewable energy; waste, water and material recycling; CO₂ emissions reduction; air, water, noise or soil pollution reduction during the consumption by the end user; recycling of a product after use; extending product life through longer-lasting, more durable products.
- 3 The CIS questionnaire includes a question about the perceived importance of 'Government grants, subsidies or other financial incentives for environmental innovations'. However, we did not include it in our models because it is a subjective perception rather than the actual public aid received by a firm.
- 4 This information was available at EUROSTAT data on 'Air emissions accounts by industry and household'.
- 5 We created a new enterprise classification by sectors, by aggregating the available NACE a classification according to the technology intensity of sectors [see Eurostat indicators of HT industry (OECD, 2003)].
- 6 More details and results about the robustness-check strategy are available upon request.