

Eco-innovation strategies: a panel data analysis of Spanish manufacturing firms

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Abstract:

This paper examines the determinants of eco-innovation strategy in Spanish manufacturing firms. Using panel data of 3,201 Spanish firms for the period 2008–2014, we specify a dynamic random probit model controlling for sample selection. The empirical results confirm that public regulations and R&D efforts encourage firms to place eco-innovation activities among their strategic priorities, however subsidies are not found to be a distinctive driver. Furthermore, we find that eco-innovation is highly persistent at the firm level, past eco-innovation behaviour being clearly of key importance in explaining the current state of a firm's eco-innovation orientation. In contrast, market factors are not found to be a key driver for eco-innovative firms.

Keywords: sustainable development, environmental innovation, eco-innovation drivers, environmental policy, persistence, panel data, Spain

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1. INTRODUCTION

In recent years, there has been increasing political and social awareness of the need to promote a European Union agenda based on smart, sustainable, and inclusive growth. This has led to a widespread consensus on the key role of innovations that positively impact the environment which, consequently, have become a goal of major EU policy strategies (EEA 2014; OECD 2011). For instance, within the Europe 2020 framework, the European Commission launched the Eco-Innovation Action Plan (EcoAP), with the aim of ensuring environment sustainability through innovation.¹

Over the past decade and especially among manufacturing firms, because of their higher environmental impact, many empirical papers have devoted attention to the drivers of eco-innovation (Carrillo-Hermosilla et al. 2009; Díaz-García et al. 2015; Ghisetti et al. 2015; Hojnik and Ruzzier 2015; Horbach 2008, 2016; Triguero et al. 2013). The primary motivation may be that eco-innovation is characterized by the problem of double externality, having both R&D spillovers and environmental externality which justify both innovation and environmental incentivizing policies (Rennings 2000).

The main purpose of this study is to analyse the drivers of designing an eco-innovation strategy in Spanish manufacturing firms. To carry out the econometric analyses, we used panel data drawn from the Spanish Technological Innovation Panel (PITEC). We applied a dynamic random probit model controlling for sample selection to an extensive sample of 3,201 Spanish firms for the period 2008–2014. In line with the existing literature, our results confirm the importance of regulatory stimulus and R&D efforts for eco-innovation firms. We also find that eco-innovation is highly persistent at the firm level, so past eco-innovation behaviour is of key importance in explaining the current eco-innovation orientation state. A firm's profile, including parameters such as its size, is key when it comes to introducing an eco-innovation strategy. In contrast, market factors are not found to be distinctive drivers for eco-innovative firms.

This study makes several contributions. Firstly, the literature has been notably reliant on German data (Rennings et al. 2006; Horbach 2008; Horbach et al. 2012; Horbach 2014) and few papers have focused on Southern Europe countries.² We consider the case of Spain, a moderate innovation country ranked number 9 in the Eco-Innovation Scoreboard (Eco-IS 2015) but, as compared to European countries such as Netherlands, Finland and Germany, a country with both a relatively low level of environmental regulation stringency and a low customer awareness of green products. The specific Spanish characteristics which distinguish it from other European countries make this analysis well worthwhile. Secondly, the econometric analysis on the eco-innovation literature has been mainly based on small and cross-sectional samples (Cainelli and Mazzanti 2013; Cuerva

¹ To achieve the transformation towards a sustainable and low-carbon economy, the EU has set itself targets for progressively reducing greenhouse gas emissions up to 2050 (the main roadmaps are: 2030 climate & energy framework and 2050 low carbon economy).

² For some exceptions that analyse the driver of eco-innovation in manufacturing sector in Southern Europe countries, see: Cainelli et al. (2012) for the Italian context, and del Río et al. (2015), Cuerva et al. (2014) and Cainelli et al. (2015) for the Spanish context.

et al. 2014; Horbach 2016; Horbach et al. 2012, 2013; Petruzzelli et al. 2011; Triguero et al. 2013), there being almost no use of panel data.³ The PITEC data allows us to examine long-term relationships between variables and to control for non-observable heterogeneity. Finally, we study persistence in eco-innovation over time; while this topic has received much attention in the field of Innovation Economics (Raymond et al. 2010; Tavassoli and Karlsson 2015), persistence has not previously addressed in the literature on drivers of eco-innovation strategy.⁴

The remainder of the paper is structured as follows. Section 2 consists of a literature review. Section 3 presents the database and the econometric methodology. Section 4 shows our main findings. The last section presents our conclusions and some policy recommendations.

2. DRIVERS FOR ECO-INNOVATION STRATEGY

Some theoretical approaches are used in the literature to explain the main determinants of adopting an eco-innovation strategy.⁵ Due to the particularities of eco-innovation highlighted above, it is widely accepted that a theory of innovation which includes technology push and demand factors as the main drivers is not enough in exploring the decision to design an eco-innovation strategy. Hence, numerous studies emphasize that innovation theory needs also to analyse the role of regulatory and institutional factors (Horbach 2008; Jaffe and Palmer 1997; Porter and Linde 1995; Rennings 2000; Rennings et al. 2006). In particular, Horbach (2008) proposes the main elements of an environmental innovation theory that includes demand side, supply side and environmental policy influences as drivers of eco-innovations.⁶

³ Contributions using panel data do exist, but they have different particularities: 1) Some are analysed at the industry level, rather than at the firm level as in our study (Del Río et al. 2011; Jaffe and Palmer 1997). 2) Some have a different analytical focus, for instance Elsayed and Paton (2005) who investigate the economic effects of environmental innovations. 3) Others have a similar focus to the present study, but fail to fully exploit the panel approach, merely using selected variables from a few earlier waves, or even the most recent one (Horbach 2008; Cainelli, De Marchi, and Grandinetti 2015).

⁴ For a few exceptions see: Horbach (2008) who shows that being innovative in the past increases the probability of being eco-innovative in the present or the future (through a dummy variable indicating whether the firm was an innovator in the preceding panel wave) and, more recently, Mothe and Nguyen-Thi (2016) who analyse whether persistent open knowledge search leads to more EI than sporadic search. However, because of the lack of firm-level panel data, none of them fully exploit the methodology to examine persistence.

⁵ It is worth mentioning that there is no theoretical framework consensus in the literature, consequently each approach underlines some drivers and rejects others. The different approaches are not mutually incompatible and should be combined. For an overview of the subject see, for example, Aykol and Leonidou (2015) and Hojnik and Ruzzier (2015).

⁶ This theoretical background in examining the drivers of eco-innovation has recently been adopted by other researchers (Cuerva et al. 2014; Doran and Ryan 2016; Horbach et al. 2012; Triguero et al. 2013).

The determinants of eco-innovation are also based on the resource-based view (RBV). A firm's ability to eco-innovate is traditionally linked to the role of resources and capabilities and to the pool of knowledge available within the firm (Cainelli et al. 2012; Horbach et al. 2012; Triguero et al. 2013). Resource-based theory highlights the importance of a firm's internal resources; in contrast, more recently, the evolutionary perspective emphasizes the importance of innovation systems, the dynamic interaction between different actors, and the internal and external factors influencing the innovation process (Nelson and Winter 1982). Several studies have identified the positive effects of incorporating external knowledge and, as compared to technological innovations, eco-innovation activities seem to require more external sources of knowledge and information (Cainelli et al. 2015; De Marchi 2012).

Furthermore, taking into account the resource-based and evolutionary perspective approaches, some researchers have categorized the drivers of eco-innovation as internal and external (Cainelli et al. 2015; Carrillo-Hermosilla et al. 2009; Del Río 2009; Demirel and Kesidou 2011; Sáez-Martínez et al. 2016). Internal factors refer to resources such as technological capabilities, qualified employees or financial resource, while external factors refer to a firm's interaction with other agents through cooperation, collaboration, networks and market relations.

Many of the studies which examine the driving forces of environmental orientation of the firms lack a theoretical framework (Aykol and Leonidou 2015; Del Río et al. 2016). Hence, following the Horbach (2008) classification, we examine the drivers of eco-innovation strategy from the perspective of the supply side, demand side, environmental policy, as well as the firms' structural characteristics from internal and external perspectives. The Horbach classification and internal and external factors can be combined (Del Río et al. 2015). As a result, technology push factors can be internal (firm technological capabilities) or external (cooperation and networks). Public policies can be market-pull (regulations) or a supply-push (subsidies). Finally, market demand (consumers) would be external.⁷

Technology push factors

The first group of factors for designing an eco-innovation strategy, technology push factors, are linked to the development of technological and organizational capabilities. The most important factors to build up such technological capabilities are investment in R&D and having qualified employees contributing to develop new products and processes (Horbach 2008; Mazzanti and Zoboli 2009; Horbach et al. 2012; Cainelli et al.

⁷ Recently, some researchers have begun to integrate the extended stakeholder view and also institutional theory (Sarkis, Gonzalez-Torre, and Adenso-Diaz 2010; Tang and Tang 2012; Tyl et al. 2015). These theories fall outside the scope of the present paper. For an overview of the subject see, for example, Aykol and Leonidou (2015) and Hojnik and Ruzzier (2015).

2015). Firms improving their firms' technological capabilities through R&D are also more likely to be updated on new environmental possibilities (Horbach 2008). Based on an extensive sample of Spanish manufacturing firms, Cainelli et al. (2015) find that the presence of an R&D structure is positively and highly correlated with the introduction of eco-innovation. A similar positive relationship is found by Cuerva et al. (2014) and (Del Río et al. 2015), both using a Spanish manufacturing sample and Horbach (2008) using German sample data.

H1: The ability of a firm to carry out eco-innovations is related to its own technological capabilities.

Significant innovation capacities within a firm (accumulation of human capital and available knowledge) may lead to further innovation success in the future. Evolutionary theory suggests that the “learning by doing” effect enhances knowledge stocks and, therefore, the probability of future innovations (Peters 2009). Following the paper of Malerba et al. (1997), an increasing number of empirical publications in innovation literature devote attention to analysing the role of persistence, in other words, whether firms which innovate once have a higher probability of innovating again in subsequent periods (Martínez-Ros and Labeaga 2009; Peters 2009; Triguero and Córcoles 2013; Deschryvere 2014). Economic theory provides at least three potential explanations of why innovation might demonstrate state dependence over time: success breeds success (successful innovations positively affect the conditions for subsequent innovations providing prosperous innovators with higher market power for an extended period), dynamic increasing returns (firms learn by innovating and develop new organizational competencies along the technological trajectory), and sunk costs in R&D investments (R&D investments over time generate a stock of physical and knowledge capital that in the longer term can be used in innovative activities and contribute to a more or less continuous flow of innovations) (Peters 2009; Raymond et al. 2010). This path dependency constitutes an important unexplored area in eco-innovation. An exception is the Horbach (2008) paper showing that being innovative in the past (in the preceding panel wave) increases the probability of being eco-innovative in the present or the future.

H2: Firms that place eco-innovation activities among their strategic priorities once have a higher probability of eco-innovate again in subsequent period.

Regarding external sources and cooperation, the literature stresses that eco-innovations are often more prone to cooperation and the search for new knowledge than are technological innovations. This is because eco-innovations are characterized by a high level of uncertainty, novelty and the need to go beyond the firm's core competences (see Horbach 2008 for Germany, Horbach et al. 2013 for Germany and France, Triguero et al. 2013 for 27 European countries, Mazzanti and Zoboli 2009 for Northern Italy and De Marchi 2012 and Cainelli et al. 2015 for Spain). The higher uncertainty in implementing an eco-innovation strategy implies a high propensity for relying on knowledge inputs from different, heterogeneous sources. For instance, De Marchi (2012) and Triguero et al. (2013) show that cooperation with public research institutes and universities becomes more relevant for eco-innovators than for other innovators. Recently, Cainelli et al. (2015) and Ghisetti et al. (2015) argue that the wider the array of knowledge sources or partners on which a firm draws, the greater the likelihood that it designs an eco-innovation strategy.

H3: External information and knowledge sources are crucial for promoting eco-innovation strategies.

Market-pull factors

The second set of drivers is related to market-pull factors. In general, studies show that the expectation of a future demand, created by environmentally conscious customers, triggers investments in environmental innovation. In particular, Horbach (2008) shows that customer demand and public pressure are the key drivers of eco-innovation. Similarly, examining nine European countries (Belgium, France, Germany, Hungary, Netherlands, Norway, Sweden, Switzerland and the United Kingdom), Wagner (2008) shows that market research on green products has a positive effect on a firm's propensity to carry out eco-innovations, since such research is likely to lead to a better understanding of profitable demand for eco-product innovations as well as in identifying eco-oriented customer segments. More recently, Triguero et al. (2013) find that increasing market demand for green products and market share are also relevant to implementing product or organizational eco-innovation. Nevertheless, in countries with low environmental awareness and low willingness to pay more for environmentally friendly products, a market pull effect will be very low or non-existent.⁸ For instance, del Río et al. (2015b) argue that demand-pull from the market is not perceptible and is not a driver for either eco-product or eco-process innovation.

H4: Market-pull is not a relevant determinant of eco-innovation orientation in Spanish firms.

Public eco-innovation policies

The last category of drivers, known as regulatory pull and push factors, is linked to the double externality problem and the role of public policies in fostering eco-innovations. In many empirical studies, regulations have been identified as an important driver of eco-innovation (see the contribution of Jaffe and Palmer 1997, one of the earliest empirical studies at the industry level in the US context or, more recently, in the European setting, Horbach et al. 2012 for Germany, Horbach et al. 2013 for Germany and France; del Río et al. 2015b for Spain, or Horbach 2016 for 19 different European countries). Hence, environmental regulation is a highly relevant motivation for eco-innovations, a result consistent with the Porter-hypothesis (Porter and Linde 1995). However, the role of environmental regulations in promoting eco-innovation differs between developed and developing countries. In developed countries, regulations may be observed by managers

⁸ According to the Special Eurobarometer (European Commission 2011, 2014), Spain has improved its ranking in regard to willingness-to-pay more for eco-products, but it still ranks below the EU average. For instance, in the Special Eurobarometer survey 2011, 60% of Spanish citizens agree that they would be ready to buy environmentally friendly products even if they cost a little bit more, while in the Special Eurobarometer survey 2014 this proportion had risen to 73%. However, the respective percentages in other countries are higher than in Spain: Sweden (89%, 94%), Denmark (81%, 87%), Germany (76%, 80%), Romania (65%, 75%).

more strictly than they are in developing countries (Tsai and Liao 2017). In this respect, Spain lies at an intermediate point.

However, the impact of supply push instruments, such as subsidies, on eco-innovation is not always clear in the literature. Horbach et al. (2012) and Horbach (2008) find a positive and statistically significant influence of subsidies on eco-innovation. Similar results are found by del Río et al. (2015a) and De Marchi (2012). Nevertheless, this variable does not seem to be especially important for eco-innovation either in Horbach et al. (2013) using a sample from the Community Innovation Survey (CIS 4) for France and Germany, or in Triguero et al. (2013).

H5: Public policies, whether in the form of environmental regulation or subsidies, increase the likelihood of being a firm with eco-innovation orientation.

3. DATABASE AND METHODOLOGY

3.1 Database

We use firm level data from PITEC which has emerged as the key data source for European countries, is one of the most used datasets in innovation studies, and has recently been applied to studying environmental concerns (Cainelli et al. 2015; Del Río et al. 2015; Horbach 2016; Jové-Llopis and Segarra-Blasco 2018).

PITEC compiled successive Spanish CIS waves and is characterized by its time dimension. It has panel data for the period 2003–2014, making it possible to analyse long-term relationships between variables, and to control for standard econometric issues, such as unobserved heterogeneity and simultaneity problems that are hard to detect in simple cross-sectional data or time series (Baltagi 2008). However, PITEC has some weakness. One of its limitations is the subjective nature of many of the questions addressed to the firm's management or those responsible for R&D departments. Nevertheless, Mairesse and Mohnen (2005) provide evidence that the subjective measures of innovation surveys tend to be consistent with more objective measures of innovation.

Our final sample has been subjected to a filtering process. The main filters were as follows: 1) the data referred the period 2008–2014, because eco-innovation motivation questions were not included in the survey until 2008; 2) firms from the manufacturing sectors were analysed; 3) firms that reported confidentiality issues, mergers, employment incidents and so on were not incorporated in the sample. After all filtering, our empirical analysis is based on a panel of 3,201 Spanish firms for the period 2008–2014. About half of firms in the sample design an eco-innovation strategy which shows an increasing trend among Spanish firms to have some concern for environmental damage and energy efficiency.

3.2 Econometric methodology

In order to model the dynamic process of designing an eco-innovation strategy for Spanish manufacturing firms, we apply a dynamic probit model correcting by sample selection arising from the exclusion of non-innovative firms from the analysis (Heckman

1979).⁹ To correct sample selection bias and endogeneity problems we apply a two-step procedure: the first stage equation -selection equation- and the second stage equation -outcome equation-. In addition, to investigate persistence in eco-innovation, we follow a dynamic approach in the analysis based on the Wooldridge (2005) correction that accounts for the lag and initial conditions of the dependent variables.

Innovation decision (selection equation):

$$technological\ innovation_{it}^* = \beta_{11}X_{it-1} + \beta_{12}Z_{it-1} + \alpha_{1i} + \varepsilon_{1it} \quad \text{Eq. [1]}$$

$$innovative_{it} = 1 \text{ if } innovative_{it}^* > 0, 0 \text{ otherwise}$$

Eco-innovation orientation (outcome equation):

$$eco - inn_{it}^* = \beta_{21}eco - inn_{it-1} + \beta_{22}Y_{it-1} + \beta_{23}Z_{it-1} + \alpha_{2i} + \varepsilon_{2it} \quad \text{Eq. [2]}$$

$$eco - inn_{it} = 1 \text{ if } eco - inn_{it}^* > 0, 0 \text{ otherwise}$$

Equation [1] estimates the probability that a firm innovates depending on a set of determinants related by the current literature.¹⁰ *Technological Innovation_{it}* is a binary variable that takes the value 1 if firm *i* introduce a technological innovation between *t* and *t-2*. As explanatory variables (X), which are specifics in this equation, we include the innovation input such as whether the firm invests in internal or external R&D, the different sources of information for innovation activities (internal, market, institutional and other sources), whether the firm cooperates or not with other agents, whether the firm receives public funds at regional, national or EU level and whether the firm exported at least part of its production. As the selection equation should contain at least one variable that is not in the outcome equation, we use this latter variable (*export*) as an exclusion restriction. We assume that being involved in international trade affects the likelihood of being an innovative firm, but it has no effect on being an eco-innovative firm.¹¹ The

⁹ As is well known, the structure of the CIS, on which the PITEC survey is based, applies a filter to the questions asked to firms: that is, only innovative firms are required to complete the whole questionnaire. Thus, since, as the questions on eco objectives of the firm are posed to innovative firms only (i.e. that have introduced technological innovation), this implies the risk of a selection bias in our case. Our dependent variable is observable only for innovative firms only. To address this issue, we carry out a Heckprobit model which accommodates the binary nature of our dependent variables.

¹⁰ See for instance: Vega-Jurado et al. (2008); Segarra-Blasco (2010); Hashi and Stojčić (2013) and Mate-Sanchez-Val and Harris (2014).

¹¹ Several contributions in the literature suggest that export is not a factor when explaining the decision to be green (Del Río et al. 2017; Horbach 2008), whereas it has been demonstrated that being active in international markets supports the decision to innovate (Becheikh et al. 2006; Hashi and Stojčić 2013). Since the two phenomena of innovating and eco-innovating are quite similar it is very difficult to identify those variables that could affect the innovation decision per se, but not the adoption of eco-innovation conditional on the decision to perform innovation activities.

residuals of this regression are used to construct a selection bias factor, which is equivalent to the Inverse Mill's Ratio. This factor accounts for the effects of all unmeasured characteristics which are related to the selection variable. The Inverse Mill's Ratio is introduced as an extra explanatory variable in the second stage of the Heckman procedure, which consists of estimating the eco-innovation orientation [Eq. 2].

Equation [2] measures the probability of designing an eco-innovation strategy. $Eco-inn_{it}$ is a binary variable that takes the value 1 if firm i states that an eco-innovation motivation has been high or medium important between t and $t-2$.¹² $Eco - inn_{it}^*$, the second latent variable, may be observed only when $innovate_{it}^*$ is equal to 1. To test Hypotheses 1–5, we use the set of explanatory variables shown in Table 1. As explanatory variables (Y), which are specifics in this equation, we include technology push factors such as R&D effort, whether a firm reported having cooperated on innovation with other partners and the breadth of sources of information for innovation activities (internal, market, institutional and other sources). For the market market-pull factors we consider two innovation objectives, namely an entry to the new markets and an increase in market share. And concerning the environmental policy influences, we capture regulation and subsidies policy measures.

INSERT TABLE 1 HERE

In addition, both equations include different common sets of control variables (Z). We introduce firm characteristics such as firm size and whether the firm belongs to a group. We also include industry and time dummies to control differences in the probability of being an innovator and an eco-innovator across sector-specific market or technological conditions and macro differences over time respectively. The inclusion of this set of covariates should mitigate the potential omitted variables bias in our econometric estimations. Finally, α_i is the time-invariant unobserved individual effects and ε_{it} is the idiosyncratic error term. In the regression analyses, we lag explanatory variables by one period to mitigate endogeneity problems deriving from reverse causality.

To investigate persistence in eco-innovation, we consider a model of eco-innovative behaviour in a dynamic panel data framework where binary responses are regressed on lagged responses. $Eco - inn_{it-1}$ is an indicator for eco-innovation during the previous period and captures the previous eco-innovation experience; β_{21} is the parameter of interest which indicate the level of persistence in the dependent variable. A positive and statistically significant estimate of β indicates the presence of eco-innovation persistence, which may occur for two reasons: because of state dependence (true state dependence) or

¹² In 2008, the panel survey introduces the following question: “*Innovation activities carried out in your firm could be oriented to different objectives, how important were each of the following objectives for your innovation activities during the three last years?*” In total 16 objectives were asked. In this set of objectives, there are two that can be strongly linked to the environmental orientation of the firm: the reduction in environmental impacts and the decrease in energy consumption per unit produced.

because of unobserved effects or omitted variables that are correlated over time (spurious dependence).

The estimation of dynamic panel data models poses two main problems: the treatment of unobserved individual effects, and the so-called initial conditions problem. Modelling the unobserved individual effects through fixed effects, in which the individual specific effect is correlated with the independent variables, leads to the ‘incidental parameters’ problem (Neyman and Scott 1948), which results in inconsistent maximum likelihood estimators when the number of periods is small. Using FE is not recommended if the dataset is characterized by the ‘small T, large N’, which is the case in our dataset (Nickell 1981). For this reason, the literature generally assumes a random effects specification in this kind of analysis (Raymond et al. 2010; Wooldridge 2010).

The second problem to how to handle concerns regarding the initial conditions. The simplest assumption is to take the initial conditions to be exogenous, but there are good reasons to believe that many firms in our sample did not start their eco-innovation processes at the beginning of the period of this study, i.e., 2008. This means that the initial condition ($eco - inn_{i0}$), is presumable correlated with both future realizations of the variable (due to state dependence), and with the unobservable individual term (given that the unobservable term is part of the process that generates the variable). Therefore, the lagged dependent variable would be correlated with the unobservable term which would lead, not only to inconsistent estimators, but also to overestimation of the state dependence effect (unless the first observation in the process, the initial condition, is accounted for).

The literature on nonlinear dynamic panel data models contains estimation techniques that properly handle these problems (Rabe-Hesketh and Skrondal 2013; Skrondal and Rabe-Hesketh 2014; Wooldridge 2005). Specifically, Wooldridge (2005) suggests a conditional maximum likelihood approach, where the individual effect is assumed to depend on the initial conditions of the dependent variable ($eco - inn_{i0}$), and all lag values of the time-varying explanatory variables (excluding the initial value). In practice, researchers often use a constrained version of the model where the lags of exogenous variables are replaced by the time average of each exogenous variable \bar{x}_i namely:¹³

$$\alpha_{2i} = \delta_0^o + \delta_1^o eco - inn_{i0} + \delta_2^o \bar{Y}_i + \delta_3^o \bar{Z}_i + \mu_{2i} \quad \text{Eq. [3]}$$

where \bar{Y}_i and \bar{Z}_i represents the means of time-variant exogenous variables and $eco - inn_{i0}$ pertains to the first available observation for each firm. δ_1^o captures the dependence of the individual effects on the initial conditions. μ_i is assumed to be

¹³ These terms, known as Mundlak means, refers to Mundlak’s (1978) proposal to relax the assumption that the observed and unobserved variables are uncorrelated.

distributed $N(0, \sigma_u^2)$ and independent of the explanatory variables, the initial conditions, and the idiosyncratic error term ε_{it} .¹⁴

Substituting Equation [3] into Equation [2] gives:

$$eco - inn_{it}^* = \delta_{21}eco - inn_{it-1} + \beta_{22}Y_{it-1} + \delta_0^o + \delta_1^o eco - inn_{i0} + \delta_2^o \bar{Y}_i + \delta_2^o \bar{Z}_i + \mu_{2i} + \varepsilon_{2it} \quad \text{Eq. [4]}$$

This econometric procedure gives rise to the main relevant results of the next section.

4. MAIN RESULTS

In this section, we present estimation results from the dynamic random probit model corrected for sample selection. The first step in our empirical model was to estimate the selection equation capturing the factors explaining the introduction of product or process innovations, *eco* or not *eco* (Table 2). From the estimation of this probit model, we obtained the correction terms (the inverse Mill's ratio) which was included in the second stage to account for the selection bias caused by the fact that we only observed the *eco*-innovation orientation for firms that innovate. The significance of the inverse Mill's ratio found confirmed the necessity of correcting for sample selection bias and the appropriateness of this two-step method versus the standard probit one.

INSERT TABLE 2 HERE

Table 3 focused on the study of the factors correlated with *eco*-innovation orientation propensity. In addition to general *eco*-innovation results, as a robustness check, we reported the results obtained by estimating focal *eco*-innovation strategies (reduction in environmental impacts and reduction in energy consumption strategies separately). In order to show the importance of accounting for individual effects and handling the initial conditions problem we present estimation results for two variants of the dynamic probit model.¹⁵ Specifically, in the first pair of columns we report the estimation of the dynamic random effect probit model taking into account the unobserved individual heterogeneity, and assuming the initial conditions to be exogenous. These results are contrasted with the estimates in the second pair of columns resulting from estimation of the model with

¹⁴ The approach considered in Eq. [3] allows the individual effects to be correlated with the regressors. However, because of the lack of variation over time (within variation) in our variables (see Appendix 4), we were unable to identify δ_2^o , and δ_3^o . Consequently, we followed the strategy adopted by Raymond et al., (2010) and assumed that the unobserved individual effects are correlated only with the initial values of $eco - inn_{it}$.

¹⁵ As is observed, the statistical significant of the panel-level variance component versus the total variance (ρ) indicates that the random effects estimator is preferred to the pooled probit estimator.

individual effects correlated with the initial conditions. The estimation results are very similar for both model variants.

INSERT TABLE 3 HERE

The results show that there is a positive relationship between technology push factors and a firm's likelihood of developing an eco-innovation orientation (Hypothesis 1). As far as the internal R&D is concerned, the results suggest that Spanish eco-oriented innovators do differ from non-eco-oriented innovators in terms of expenditures on innovation activities per worker in both types of eco-innovation orientation. This results are in line with empirical works from the manufacturing samples of Horbach (2008) and De Marchi (2012).

In terms of temporal persistence, the empirical analysis reveals that past eco-innovation behaviour is an important driver of current eco-innovation status, providing support for Hypothesis 2. As previously mentioned, any apparent persistence of eco-innovation might be spurious. The existence of true persistence can be ascertained only after accounting for individual effects and handling properly the initial conditions. Once this is done, two main conclusions arise. First, the coefficients of the lagged dependent variables are positive and significant for both types of eco-innovation, revealing that engaging in eco-innovation orientation during the previous year has a positive effect on the probability of being a green innovator in the current year. Hence, the results suggest a significant state dependence effect for eco-innovation strategies. Second, in line with previous findings in the literature, the hypothesis of exogenous initial conditions leads to overestimation of the degree of persistence.¹⁶

Results on external innovation resources are less straightforward; support for Hypothesis 3 is unclear. The coefficient of external R&D effort is positive and significant. In other words, among manufacturing firms, buying external R&D services is more relevant in spurring the introduction of green innovations than are other innovations. Regarding the impact of cooperation, in contrast to del Río et al. (2015a) and Horbach (2008), we find the role of participating in cooperative projects is not a determinant of triggering an eco-innovation motivation. As we also found, Horbach et al. (2013) and Cuerva et al. (2014) were unable to confirm a positive relationship between an open innovation strategy and eco-innovation. They found that firms that follow an in-house strategy experience greater environmental innovation. Concerning sources of, in particular the variety of sources of information, is positively and significantly correlated with the probability of designing an eco-innovation strategy between both types of eco-motivation. This suggests that breadth of innovation sources may increase the firm's coverage of the multiple knowledge needs entailed by the multi-dimensionality of eco-innovation (Mothe and Nguyen-Thi 2016).

In contrast to the analyses made for other countries, the market does not provide a demand-pull for eco-innovation. The non-significant signs of the variables reflecting the importance given to maintaining or increasing market share and entry to new markets do

¹⁶ Interestingly, the driver with the highest impact refers to the persistence of eco-innovation orientation, followed by environmental policies such as regulations.

not confirm the role of demand-pull factors in eco-innovation (Hypothesis 4). The estimations by focal eco-strategies show the robustness of this result and in neither of the two cases is the parameter obtained significant. This is in contrast to the findings of Horbach et al. (2013), who examined German and French data, of Veugelers (2012), who investigated data for Flanders. However, our results concur with those of Del Río et al. (2015) who find no evidence for market factors. The growing environmental awareness among Spanish customers in recent years, although still low as compared to other European countries, may explain the lack of statistical significance of the demand-pull variable.

In line with other contributions in the literature, our results show that regulation and environmental public policies are crucial to eco-innovation (De Marchi 2012; Del Río et al. 2015; Demirel and Kesidou 2011; Horbach 2008; Horbach et al. 2013). Looking first at the regulatory variable, we note that existing regulation is a positive and significant driver for Spanish firms to eco-innovate in both types of eco-orientation. However, the relative magnitudes of this impact vary across the types of eco-innovation considered. In line with Costa-Campi et al. (2015), we also observe that innovation behaviour with the objective of reducing energy consumption is affected by regulations. Comparing the different type of subsidies (local, national and EU), it seems that these variables have no significant effect on the decision to undertake an eco-innovation strategy.

Finally, concerning a firm's characteristics, in line with (Carrillo-Hermosilla et al. 2009; Del Río et al. 2016; Hojnik and Ruzzier 2015), our results show that larger manufacturing firms are more likely to design an eco-innovation strategy (Costa-Campi et al. 2015; De Marchi 2012; Del Río et al. 2015). In contrast, belonging to a group of firms shows no relationship to being a green firm in any eco-innovation orientation (Cainelli and Mazzanti 2013; Doran and Ryan 2016).

4.1 Robustness check

To verify the robustness of our results, we ran further regressions with different specifications of our main dependent variables. Firstly, we transformed the dependent variable into a binary one, taking the value 1 when a firm considers any of the two eco-objectives (reduce environmental impacts or reduce energy consumption) to have high importance and 0 otherwise. Second, as mentioned, the eco-innovation motivation variables in the PITEC database are measured using a variable with four values (high, medium, low and null impact). As a sensitivity analysis, we estimated the model when the intermediate answers were also taken into account. Hence, we ran a model using a random-effects ordered probit regression with sample selection.

The results clearly show that there are hardly any changes regarding the sign and significance of the explanatory variables in the models when using a different specification of the dependent variables, from dichotomous with high and medium intensity to high intensity only and from a dichotomous specification to a multinomial one (four categories).¹⁷ Hence, the results shown in the previous section are deemed robust.

¹⁷ Available from the authors on request; not reported here due to space limitations.

5. CONCLUSIONS AND PUBLIC POLICY RECOMMENDATIONS

The paper explores the determinants of designing an eco-innovation strategy in a Spanish context. To overcome at least some of the limitations of earlier studies, which have used mainly cross-sectional databases, the empirical analysis carried out in this paper is based on the Technological Innovation Panel (PITEC). Hence, it provides novel results related to the temporal dimension in the literature on eco-innovation orientation.

The availability of longitudinal, firm-level panel data allows us to consider the dynamic features of eco-innovation orientation and focus on the roles of persistence and individual unobserved heterogeneity of firms, a topic that has received much attention in the innovation literature, but which is still largely unexplored in the eco-innovation context. In estimating the dependence of past eco-innovation performance and the drivers of both general eco-innovation and focal eco-innovation strategies, such as reducing environmental impacts and reducing energy consumption, we introduced lagged dependent variables as explanatory terms and used a methodology to control for the initial conditions and unobserved heterogeneity: a random effect dynamic probit model controlling for possible sample selection based on adapting Wooldridge's (2005) proposal.

The advantage of accessing a sample of Spanish manufacturing over seven years allows us to analyse in depth the nature and effects of some factors that concern the capacity of manufacturing firms to carry out eco-innovation strategies. The nature of our panel data shows that eco-innovation is not a sporadic activity. On the contrary, it is a decision that is characterized by its intensive path dependence. In general, all eco-innovation strategies, both those that pursue the reduction of environmental impacts, as well as those related to energy efficiency, imply considerable levels of temporary persistence and requires a long implementation period.

Regarding the factors that increase the capacity of Spanish manufacturing firms to engage in eco-innovation strategies, the results obtained are consistent and robust. Technological push forces and environmental regulations appear as the main drivers of eco-innovation initiatives in Spanish firms. Internal and external R&D efforts, and greater breadth of knowledge sources, show a positive and significant effect on the capacity of Spanish firms to engage in eco-innovation.

When we observe the effect of external drivers that can foster eco-innovation, we found that environmental regulations play a key role fostering environmental actions. However, public subsidies from different government levels—regional, state and EU institutions—do not play a relevant role in enhancing the capacity of firms to design eco-innovation strategies. In addition, pull demand drivers are not found to foster eco-innovation strategies in Spanish manufacturing firms. In sum, the temporal persistence of eco-innovation, the key role of R&D activities and the direct impact of public regulation offer crucial information for the design of future public policies. Given that there are few differential drivers for each eco-innovation type, our analysis questions whether differential support should be provided for reducing environmental impacts as opposed to energy efficiency.

This analysis carries an important policy implication. For policy-makers, this study gives new insights into the drivers of eco-innovation strategies in manufacturing firms and emphasizes the temporal dimension. First, since eco-innovations are characterized by the double externality problem, public policy still retains a relevant role. Traditional environmental policy, in terms of existing regulations, is effective in the Spanish context in driving eco-innovation orientation in all types of eco-innovation strategies considered, especially for energy efficiency orientation where the impact is higher. However, the lack of effectiveness of subsidies suggests a change in the current regulatory framework.

Second, given that we cannot rely either on the market-pull factor or on cooperation as main drivers of eco-innovation, there remains an important role for public policies in triggering an eco-innovation orientation. The role of governments in promoting eco-innovation concerns, not only by new regulatory or economic instruments, but also by improving consumer awareness, facilitating partnerships and encouraging cooperation.

Third, as mentioned above, our analysis shows a high persistence in eco-innovation orientation. The results are of considerable interest for any public policy targeting innovation and eco-innovation. Government agencies or other institutions could provide incentives to engage in eco-innovation activities, without ignoring the fact that initiatives that pursue different objectives linked to eco-innovation are complementary and have a considerable temporal dependence.

The complex policy challenge based on support for eco-innovation requires a coordinated approach, one which simultaneously integrates innovation, research and environmental policy. As eco-innovations have both environmental and innovation externality (Rennings 2000), environmental policies can only be one component of the package of instruments needed to promote eco-innovation strategies. Thus, the promotion of eco-innovation requires a balanced strategy combining different policy tools. However, fostering an eco-innovation orientation consists, not only in applying specific instruments, also in implementing a policy framework that is well defined, ongoing, and based on consistent economic and environmental criteria (Economic Commission for Europe (UNECE 2011). Spain's relatively low level of R&D intensity (in particular in regard to government environmental and energy R&D investments), the low proportion of R&D personnel and researchers in the workforce, the context of political instability and the lack of organisation and collaboration at institutional and governance levels, all constitute barriers for eco-innovation that public policies should attempt to overcome (EIO 2015).

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TABLES

Table 1

Summary statistics of the variables used in the estimations

| <i>Dependent variables</i> | <i>Variable definitions</i> | <i>Mean (σ)</i> |
|-------------------------------------|--|-----------------------------------|
| Technological innovation | Dummy variable which takes the value 1 if the firm has introduced technological innovations or non-technological innovations; 0 if not | 0.79(0.40) |
| Eco-innovation strategy | Dummy variable that takes a value equal to 1 if the firm innovation objective has a high or medium orientation towards reducing environmental impact or energy consumption per unit produced; 0 if not | 0.53 (0.49) |
| Reduce environmental impacts | Dummy variable that takes a value equal to 1 if the firm innovation objective has a high or medium orientation towards reducing environmental impact; 0 if not | 0.47(0.50) |
| Energy efficiency | Dummy variable that takes a value equal to 1 if the firm innovation objective has a high or medium orientation towards reducing energy consumption per unit produced; 0 if not | 0.40(0.48) |
| <i>Independent variables</i> | | |
| <i>Environmental policy</i> | | |
| Regulation | Dummy variable that takes a value equal to 1 if the firm innovation objective has a high or medium orientation towards meet regulatory requirements; 0 if not | 0.52(0.50) |
| Subsidies | Local subsidies: dummy variable that takes a value equal to 1 if the firm receives any public financial support for innovation activities from local authorities; 0 if not | 0.20(0.40) |
| | National subsidies: dummy variable that takes a value equal to 1 if the firm receives any public financial support for innovation activities national authorities; 0 if not | 0.23(0.42) |
| | EU subsidies: dummy variable that takes a value equal to 1 if the firm receives any public financial support for innovation activities from the EU; 0 if not | 0.03(0.19) |
| <i>Technology push factors</i> | | |
| Internal R&D effort | Expenditures in internal R&D activities per worker | 3802.99(8661.55) |
| External R&D effort | Expenditures in external R&D activities per worker | 899.81(5749.14) |
| R&D Cooperation | Dummy variable that takes a value equal to 1 if the firm cooperates with other agents during; 0 if not | 0.34(0.47) |
| Sources of information | Internal sources: dummy variable which takes a value equal to 1 if information from sources within the enterprise or group has high importance; 0 if not | 0.76(0.42) |
| | Market sources: dummy variable which takes a value equal to 1 if information from suppliers, clients, competitors or private R&D institutions has high importance; 0 if not | 0.73(0.44) |
| | | 0.35(0.47) |

| | | |
|-----------------------------|---|----------------|
| | Institutional sources: dummy variable which takes a value equal to 1 if information from universities, public research organizations or technology centres has high importance; 0 if not | 0.46(0.49) |
| | Other sources: dummy variable which takes a value equal to 1 if information from conferences, scientific reviews or professional associations has high importance; 0 if not | |
| Breadth of sources | Variable ranging from 0 to 11, depending on the number of sources of information (enterprise, suppliers, clients, competitors, private R&D institutions, universities, public research organizations, technology centres, conferences, scientific reviews and professional associations). | 1.67(1.74) |
| <i>Market-pull factors</i> | | |
| New market | Dummy variable that takes a value equal to 1 if the firm innovation objective has a high or medium orientation towards entering new markets; 0 if not | 0.63(0.48) |
| Market share | Dummy variable that takes a value equal to 1 if the firm innovation objective has a high or medium orientation towards increasing or maintaining market share; 0 if not | 0.64(0.47) |
| <i>Firm characteristics</i> | | |
| Group | Dummy variable that takes a value equal to 1 if the firm belongs to a group; 0 if not | 0.50(0.49) |
| Size | Log of the total number of firm's employees | 207.37(557.51) |

Table 2
Probability of innovation in Spanish manufacturing firms (selection equation)
Period 2008–2014.

| | Manufacturing |
|-----------------------------|------------------------|
| Internal R&D effort $t-1$ | 0.0858*** (0.00632) |
| External R&D effort $t-1$ | 0.0146* (0.00722) |
| R&D Cooperation $t-1$ | 0.301*** (0.0488) |
| Internal sources $t-1$ | 0.689*** (0.0494) |
| Market sources $t-1$ | 0.565*** (0.0487) |
| Institutional sources $t-1$ | -0.145** (0.0492) |
| Other sources $t-1$ | 0.162*** (0.0450) |
| Local subsidies $t-1$ | 0.0919 (0.0536) |
| National subsidies $t-1$ | 0.215*** (0.0543) |
| EU subsidies $t-1$ | 0.0454 (0.116) |
| Size $t-1$ | 0.0645* (0.0252) |
| Group $t-1$ | -0.0520 (0.0550) |
| Export $t-1$ | 0.128** (0.0443) |
| Constant | -0.770 (0.404) |
| Log likelihood | -6303.0 |
| Wald test of χ^2 | 2335.3 |
| Prob > χ^2 | 0.000 |
| σ_u | 1.0872 (0.3265) |
| Rho (ρ) | 0.5417 (0.0149) |
| Observations | 19,206 |

Estimations control for time and industry dummies. Standard errors in brackets. *, ** and *** correspond to significance levels of 1%, 5% and 10%, respectively. Marginal effects are calculated for each case, and then averaging over all of the cases (average marginal effects)

Table 3
Probability to performing eco-innovation strategies in Spanish manufacturing firms (outcome equation).
Period 2008-2014.

| | Eco-innovation strategy | | Reduce environmental impacts | | Energy efficiency | |
|------------------------------------|------------------------------|------------------------------------|------------------------------|------------------------------------|------------------------------|------------------------------------|
| | Exogenous initial conditions | Correlated with initial conditions | Exogenous initial conditions | Correlated with initial conditions | Exogenous initial conditions | Correlated with initial conditions |
| <i>Persistence</i> | | | | | | |
| Eco-innovation strategy $t-1$ | 1.428*** (0.0405) | 1.143*** (0.0433) | | | | |
| Reduce environmental impacts $t-1$ | | | 1.505*** (0.0422) | 1.109*** (0.0449) | | |
| Energy efficiency $t-1$ | | | | | 1.493*** (0.0365) | 1.178*** (0.0392) |
| <i>Initial conditions</i> | | | | | | |
| Eco-innovation strategy | | 0.607*** (0.0448) | | | | |
| Reduce environmental impacts | | | | 0.723*** (0.0485) | | |
| Energy efficiency | | | | | | 0.613*** (0.0454) |
| <i>Technology-push factors</i> | | | | | | |
| Internal R&D effort $t-1$ | 0.0431*** (0.00446) | 0.0445*** (0.00493) | 0.0422*** (0.00445) | 0.0438*** (0.00507) | 0.0334*** (0.00460) | 0.0339*** (0.00507) |
| External R&D effort $t-1$ | 0.0121** (0.00455) | 0.0108* (0.00506) | 0.0121** (0.00442) | 0.0124* (0.00507) | 0.00992* (0.00445) | 0.0112* (0.00493) |
| R&D Cooperation $t-1$ | 0.0534 (0.0312) | 0.0411 (0.0345) | 0.0764* (0.0304) | 0.0673* (0.0346) | 0.0493* (0.0306) | 0.0578* (0.0336) |
| Breadth sources innovation $t-1$ | 0.0394*** (0.00916) | 0.0378*** (0.0102) | 0.0341*** (0.00875) | 0.0333*** (0.0100) | 0.0278** (0.00868) | 0.0239* (0.00962) |
| <i>Market pull factors</i> | | | | | | |
| New market $t-1$ | 0.0695 (0.0391) | 0.0628 (0.0425) | 0.0727 (0.0387) | 0.0734 (0.0432) | -0.0178 (0.0394) | -0.0162 (0.0426) |
| Market share $t-1$ | -0.0233 (0.0397) | -0.0258 (0.0433) | -0.000752 (0.0394) | -0.00666 (0.0441) | 0.0207 (0.0401) | 0.0163 (0.0434) |
| <i>Environmental policy</i> | | | | | | |
| Regulation $t-1$ | 0.310*** (0.0323) | 0.253*** (0.0354) | 0.203*** (0.0336) | 0.176*** (0.0376) | 0.247*** (0.0306) | 0.228*** (0.0333) |
| Local subsidies $t-1$ | 0.0489 (0.0340) | 0.0537 (0.0374) | 0.0143 (0.0329) | 0.0232 (0.0372) | 0.0547 (0.0329) | 0.0593 (0.0360) |
| National subsidies $t-1$ | 0.0349 (0.0339) | 0.0519 (0.0372) | 0.0307 (0.0327) | 0.0414 (0.0369) | 0.0144 (0.0326) | 0.00874 (0.0356) |
| EU subsidies $t-1$ | -0.0205 (0.0738) | -0.0439 (0.0809) | 0.0817 (0.0721) | 0.0707 (0.0810) | -0.126 (0.0692) | -0.142 (0.0756) |
| <i>Firm characteristics</i> | | | | | | |
| Group $t-1$ | 0.0318 (0.0320) | 0.0444 (0.0373) | 0.00708 (0.0315) | 0.0213 (0.0387) | 0.0395 (0.0324) | 0.0239 (0.0378) |
| Size $t-1$ | 0.107*** (0.0144) | 0.106*** (0.0169) | 0.113*** (0.0143) | 0.118*** (0.0175) | 0.116*** (0.0145) | 0.129*** (0.0170) |
| Log likelihood | -6612.9 | -6471.8 | -6963.5 | -6791.0 | -7321.5 | -7188.7 |
| Wald test of χ^2 | 2924.2 | 3050.9 | 3156.8 | 3248.3 | 2862.5 | 3133.6 |
| Prob > χ^2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| σ_u | 0.413 (0.0374) | 0.573 (0.0336) | 0.411 (0.0397) | 0.626 (0.0336) | 0.440 (0.0365) | 0.611 (0.0319) |
| Rho (ρ) | 0.146 (0.0226) | 0.247 (0.0218) | 0.144 (0.0239) | 0.281 (0.0215) | 0.162 (0.0225) | 0.272 (0.0207) |
| Mill's ratio | 0.424*** (0.0839) | 0.353*** (0.0888) | 0.427*** (0.0849) | 0.369*** (0.0916) | 0.358*** (0.0860) | 0.332*** (0.0910) |
| Censored obs. | | | | 4,086 | | |
| Uncensored obs. | | | | 15,120 | | |
| Observations | | | | 19,206 | | |

Estimations control for time and industry dummies. Marginal effects are calculated for each case, and then averaging over all of the cases (average marginal effects). For dummy variables, change in probability for a discrete change of the dummy variable from 0 to 1. Standard errors in parentheses. *, ** and *** correspond to significance levels of 1, 5 and 10%. R&D effort and size variables are expressed in natural logarithms.