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Energy Sustainability

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WHAT ARE THE DETERMINANTS OF INVESTMENT IN ENVIRONMENTAL R&D? *

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ABSTRACT: To face the challenges posed by climate change, environmental R&D and innovation are critical factors if we hope to cut emissions; yet, investment in environmental R&D remains below the social optimum. The aim of this paper is to analyse the determinants of investment in environmental innovation and to detect the differences, if any, with the determinants of investment in general innovation. R&D investment is one of the key variables for analysing the resources devoted to innovation; however, data constraints hamper the use of this variable when examining the drivers of eco-innovation. The literature reports that demand factors in general and collaboration with stakeholders play a crucial role in generating such investment. In addition, this paper similarly examines the relationship between environmental innovation R&D expenditure and a range of policy instruments, including environmental regulation and other policy measures including R&D subsidies and environmental taxes. The empirical analysis is carried out for 22 manufacturing sectors in Spain for the period 2008–2013. To overcome problems of data availability, we construct a comprehensive database from different surveys.

JEL Codes: O30, Q50, Q58

Keywords: Environmental innovation, tax and demand instruments, panel data

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1. INTRODUCTION

The agreement reached in Paris in 2015 committed all country signatories to stem their greenhouse gas emissions over the coming century, with the objective of holding the increase in the global average temperature and, thereafter, of pursuing efforts to limit the temperature increase (UNFCCC, 2015). Europe meanwhile has revised its climate targets initially set for 2020. Thus, its 2030 framework for climate and energy calls for a 40% cut on 1990 greenhouse gas emissions compared to the 20% established in 2020 (European Commission, 2014). All this is clear evidence of the global concern for climate issues and of the steps needed to improve the environmental performance of countries around the world. In facing up to this challenge, environmental R&D and innovation represent key factors if emissions are to be cut. Indeed, the introduction of more ambitious targets requires stepping up current R&D and innovation efforts (European Commission, 2014).

Corporations are typically portrayed as being one of the main causes of the environmental problems the world faces, yet many firms are responding by adopting active roles in environmental management (Walker and Wan, 2012). While some firms merely advocate the importance of managing the environment and signal their commitment to it, others see their performance as an all-encompassing construct and tackle environmental and economic issues together by promoting green innovation. Increasing levels of public scrutiny, public pressure and public incentives, combined with stricter regulatory controls, induce firms to innovate with positive consequences for the environment (Bilbao-Osorio et al., 2012; Johnstone et al., 2008).

However, environmental innovation is affected by the problem of double externality (Rennings, 2000). The combination of the environmental externality and knowledge-market failures justifies the introduction of environmental and innovation policies to encourage the adoption of eco-innovations (Del Río et al., 2016). Although many of the determinants of environmental innovation are expected to be similar to those of general innovation (Rennings, 2000; Del Río, 2009), the empirical literature has in fact identified quite distinctive features in the case of eco-innovation (Hojnik and Ruzzier, 2015; Del Río et al., 2016). Specifically, and as a result of this double externality problem, regulation makes eco-innovation different (Del Río et al., 2015).

There has been a recent rise in interest in determining the drivers of investment in environmental innovation (Hojnik and Ruzzier, 2015; Del Río et al., 2016). As such, the aim of this paper is to contribute to this growing body of literature and to analyse the determinants of investment in eco-innovation and to detect differences, if any, with the determinants of investment in general innovation. To this end, we undertake an analysis of the drivers of environmental R&D. Indeed, while R&D investment is one of the main variables used in the field of the economics of innovation to analyse the technological activity of firms, data constraints have hampered its use for examining the drivers of investment in eco-innovation.

The literature to date reports that demand, regulation and stakeholder factors play important roles in the generation of investment in this sector (Rennings, 2000; Wagner, 2008; Kesidou and Demirel, 2012). In this same line, this paper seeks to shed further light on the relationship between environmental innovation investment and different policy instruments governing environmental innovation, that is, environmental regulations and a set of policy measures that include R&D subsidies and environmental taxes (Del Río, 2009; Horbach et al., 2012; Veugelers, 2012; Marin, 2014).

We report the results of an empirical analysis conducted for 22 manufacturing sectors in Spain for the period 2008–2013. The analysis of the determinants of R&D investment using industry-level data is especially common in the field of the economics of innovation (Cohen, 2010); however, to the best of our knowledge, such an analysis has yet to be performed for environmental R&D or eco-innovation. Industries have different technological opportunities and differ in their degree of eco-innovativeness. To overcome the lack of data, we build a comprehensive database drawing on different surveys on innovation, environmental issues and policy instruments. The use of industry-level data, although giving rise to certain limitations compared to the use of firm-level data, allows us to exploit the advantages of using panel data models. As Del Río et al. (2016) point out, econometric analyses using panel data are recommendable but they are virtually absent from the analysis of the drivers of eco-innovation owing to the unavailability of adequate data.

The rest of this article is structured as follows. The next section reviews the literature. The third section presents the model and the variables and describes the data. The fourth section discusses the main results. The last section concludes and presents some policy recommendations.

2. BACKGROUND

Businesses are coming under increasing pressure to take an active role in the achievement of greening goals alongside their more traditional financial goals (Johnstone et al., 2008). Since one of the mechanisms firms can adopt in dealing with the changing environment is that of innovation (Schoonhoven et al., 1990), green innovation represents a suitable option for countering this mounting pressure and promoting a green, sustainable environment (De Marchi, 2012; Johnstone et al., 2008).

The terms environmental innovation, green innovation and eco-innovation are used here synonymously (Tietze et al., 2011) and we adhere to the following common definition:

> "(…) innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (…) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Pearson, 2007: 7).

We adopt a simple framework for separating the four determinants of eco-innovation identified in the literature: firm strategies, technology, market/demand and regulation (Horbach et al., 2012; Horbach and Rennings, 2013). For firms to develop environmental innovations, Rennings (2000) argues that technology-push and market-pull factors alone do not provide sufficient incentives. While society as a whole benefits from environmental innovations, the costs are borne by individual firms. Despite the fact that certain environmental innovations can be marketed successfully, a firm's ability to appropriate the profits from such an innovation can be hindered if environmental benefits have the character of a public good or the corresponding knowledge is easily accessible and copied. Technology and market factors alone do not provide sufficient incentives. Consequently, the regulatory framework for environmental policies becomes another important driver of environmental innovations (Green et al., 1994, Rennings, 2000; Rennings and Zwick, 2002; Brunnermeier and Cohen, 2003; Hojnik and Ruzzier, 2015). Here, we focus specifically on policy measures and firm strategies leaving all other factors as controls.

While the world is moving towards more sustainable development, and as environmental innovation reduces the impact on the environment (at the same time inducing a high demand, according to Wagner, 2008), green innovation remains relatively new and unknown to firms (Horbach et al., 2013). Thus, while various technologies have been developed for the renewable production of energy, including solar, wind, water, and biomass sources, these technologies remain unstable and far from perfect. This means many opportunities can still be exploited and firms that successfully develop and market their green innovations can profit from being among the first-movers in this sector and from establishing green standards. The absorption of internal and external knowledge could alleviate the problems of spillover effects on potential imitators, thus overcoming threats of imitation and concerns of appropriation.

As innovative output is the product of knowledge generating inputs (Griliches, 1979), we need to determine where firms search for knowledge inputs for their eco-innovations, especially as green innovations are relatively unknown to the majority of firms (Horbach et al., 2013). Hence, here we pay particular attention to firms' sourcing strategies for green innovations, given that a successful innovation depends on how adept firms are at the identification of, deliberate search for, reaching out to, managing and implementing these promising sources (Cohen and Levinthal, 1990; von Hippel, 1988). If the wrong sourcing strategy is pursued, firms may easily lose their opportunities or competitive advantage. Thus, good knowledge sourcing can provide firms with a competitive strategy for investing in appropriate R&D or new product development and so they are better able to provide green products and boost their sales.

As Kemp et al. (1992) recognise, increasing investments in eco-innovation are influenced by a firm's capabilities – specifically, those related to organisational skills, source reduction, recycling, pollution prevention, and green product design. Recently, Demirel and Kesidou (2011) have identified a firm's organisational capabilities and its environmental management systems (EMS) as being key drivers of eco-innovation intensity. In line with these arguments, we therefore formulate the following hypotheses:

H1a: Investment in the production process to prevent pollution increases environmental R&D.
H1b: Investment in end-of-pipe solutions to prevent pollution increases environmental R&D.
H1c: The acquisition of energy products increases environmental R&D.

The green business literature usually draws a distinction between firms that adopt a proactive stance, and which consider a variety of forces other than government regulations, and firms that are compliance-driven and that merely seek to meet their legal requirements (Buysse and Verbeke, 2003). Here, the introduction of different levels of EMS can act as a facilitator factor in both the development and adoption stages of eco-innovation. Among the EMS certifications (ISO14001, ISO9001 and EMAS), only ISO14001 stimulates both stages (Hojnik and Ruzzier, 2015).

H1d: The introduction of EMS stimulates environmental R&D

The introduction of environmental regulations and the public funding of R&D are the first steps towards promoting the development of green technologies. Yet, in common with other types of innovation, the benefits of eco-innovations may accrue to society rather than solely to the adopter of these new technologies. The market failure of innovation in general is common in discussions concerning the Porter hypothesis, where the key issue is determining whether regulation drives innovation. In fact, polluting firms can benefit from environmental policies, on the understanding that well-designed, stringent environmental regulations can actually stimulate innovation (Porter and van der Linde, 1995).

Some authors argue that increased environmental regulations lead to higher costs (Walley and Whitehead, 1994), while Horbach and Rennings (2013) report no increase in employment when firms develop green innovations in response to regulations. Although the stringency of environmental policies leads to more end-of-pipe type technologies (Aragón-Correa and Sharma, 2003; Frondel et al., 2007; Hart, 1995), Rennings et al. (2004) show that the effect of these technologies on employment is negative. Other authors, including most notably Porter and van der Linde (1995), argue the contrary case. They claim that environmental regulations provide firms with increased opportunities, which are accompanied expansion and an increase in employment. Likewise, Costa-Campi et al. (2014) show that in the energy sector, norms and regulations governing the environment and matters of health and safety actually foster investment in R&D.

In the case of the Spanish pulp and paper industry, Del Río (2005) identified regulatory pressure and corporate image as the main drivers of its adoption of cleaner technology. Frondel et al. (2007) and Arimura et al. (2007) report that general policy stringency is an increasingly important driver as opposed to simple policy instruments. Moreover, stringency is particularly important for end-of-pipe technologies. On the basis of this evidence, we disentangle general regulations from environmental regulations to capture this distinction.

Thus, we explicitly separate environmental regulation centred on controlling emissions from taxes. This classification (see Wagner, 2003) places the emphasis firmly on the environmental effectiveness of the instruments. Hence, the instruments that establish emission limits and standards can be classed as command-and-control type regulations (end-of-pipe), while environmental taxes and charges and tradable emission permits or certificates are classified as market-based instruments. The latter have an economic profile since they trigger static and dynamic efficiency and internalise environmental externalities in and between markets.

H2: The use of pollution taxes increases environmental R&D.
H3: The use of stringent regulations increases environmental R&D.

Finally, recent developments regarding technological change support the idea that the use of a portfolio of instruments can help economies not only reduce the production of dirty technologies but also provide incentives to the private sector to innovate and create new, clean technologies. The presence of public support in the form of subsidies is particularly critical for developing clean technologies in the early stages since this can neutralise the advantages of older base technologies (Veugelers, 2012). Acemoglu et al. (2009) show that, while a carbon price alone could deal simultaneously with both environmental and knowledge externalities, such a course of action would represent a more costly scenario in terms of its impact on economic growth. Similarly, the use of subsidies alone results in excessively high levels of subsidies, which results in their becoming a substitute for proactive action (Yang and Oppenheimer, 2007). Therefore, we include the use of public funds as a complement of the instruments discussed above for limiting climate change.

H4: The use of public funds increases environmental R&D.

3. MODEL, VARIABLES AND DATA

3.1. Model and variables

To conduct the empirical analysis based on the framework presented above, we use the following model:

$$R\&D_{it} = \beta_0 + \beta_1 F_{it} + \beta_2 S_{it} + \beta_3 R_{it} + \mu_i + e_{it} \qquad (1)$$

where R&D refers to private environmental R&D expenditure and F, S and R are different sets of explanatory and control variables for R&D investment, in general, and for environmental R&D, in particular.

In the first set of variables, F, we include those control variables that have been identified in the literature as being determinants of general R&D expenditure at the industry-level and which have also been included in empirical analyses of eco-innovation (Del Río, 2009; Cohen, 2010; Del Río et al., 2016). First, we include two characteristics of firms, albeit at the industry-level, that may drive general investment in R&D: namely, R&D personnel intensity and the participation of foreign capital. Second, in line with the literature, we use the amount of sales to control for demand. Third, industries differ in their technological opportunities. Although there is no clear consensus regarding how best to make this concept empirically operational, the usual method has been to classify the industries according to their scientific or technological field. Here, we need to control specifically for technological opportunities related to the environment because industrial sectors also differ significantly in the degree of eco-innovativeness (Del Río et al., 2016). As a proxy we use the importance attached by a firm to the reduction of the environmental impact as an objective of their innovation policy. The assumption is that the sectors with a high number of firms attaching considerable importance to this objective will have greater environmental technology opportunities.

In the second set of variables, S, we include two types of investment to prevent pollution and a measure of the use of energy products as an intermediate input in the production process. In addition, we include information in relation to EMS (Demirel and Kesidou, 2011). These variables highlight the environmental strategies firms develop that may require investment in environmental R&D. In the case of investments to prevent pollution, we consider investment in end-of-pipe solutions and investment in the production process separately. The former corresponds to the technological solutions that firms incorporate in the existing manufacturing process and which are not essential parts of it. As such, the degree of technical advance represented by these investments is quite low as they are mainly incremental innovations. In contrast, investments in the production process correspond to new or substantially modified production facilities and they represent an integral part of the production process aimed at reducing pollution (Demirel and Kesidou, 2011).

Finally, we include a set of variables, R, to examine the effect of different policy measures on the promotion of environmental R&D. Many papers stress the importance of policy support and regulation for promoting eco-innovation (Del Río, 2009; Popp et al., 2010; Horbach et al., 2012; Veugelers, 2012; Marin, 2014). To promote environmental R&D, governments have a portfolio of instruments at their disposal and, as discussed in the previous section, they include the public financing of private R&D, energy and environmental taxes and environmental regulation. In the case of this first variable, the amount of public subsidies specifically granted to environmental R&D is not reported and, so, we employ, by way of a proxy, total public support to business R&D. Second, we distinguish between specific energy taxes and taxes with environmental objectives (pollution and resources). Finally, in line with Constantini and Crespi (2008) and Marin (2014), we use environmental pressures, measured in terms of air emissions of CO2, as a proxy for environmental regulation.

In addition to these explanatory variables, in the equations we take into account time-invariant and unobservable specific industry characteristics and time effects in order to control for cyclical change.

3.2. Data

Empirical analyses of environmental technological change have to contend with constraints on data availability (Del Río, 2009; Veugelers, 2012). These limitations refer equally to the dependent and the explanatory variables. Many variables have been used to proxy environmental innovation (Del Río, 2009), although, as in general analyses of the determinants of innovation, arguably the three most accurate are two output measures – namely, patents and the introduction of new products and processes – and one input measure – namely, R&D investment.

Patents have specific limitations for measuring eco-innovations (Veugelers, 2012). However, direct data on eco-innovations adhering to the Oslo Manual (OECD, 2005) are only available for the period 2006–2008 for the countries that in 2009 conducted a separate module on eco-innovation in their respective Community Innovation Surveys (Horbach, 2014). From these data, a number of empirical analyses have been carried out for specific countries (see, among others, Horbach et al., 2012; Veugelers, 2012; Horbach et al., 2013).

In this paper, we use environmental R&D investment at the industry-level for a set of manufacturing sectors as our dependent variable. The determinants of total R&D investment at both firm- and industry-levels have been extensively examined in the literature on the economics of innovation (Cohen, 2010). However, data on environmental R&D are very scarce (Horbach, 2014; Marin, 2014) because data on private R&D expenditure are not usually reported by technology and tend only to be available by economic sector (Veugelers, 2012).

However, in the Spanish version of the Community Innovation Survey (CIS), since 2008 firms have been asked to classify their internal R&D expenditure according to its socio-economic objective, in line with the criteria employed in the Frascati Manual (OECD, 2002). Specifically, firms are required to distribute their R&D expenditure between fourteen socio-economic objectives, according to the purpose of the R&D programme or project. One of these objectives is the control and care of the environment and it is this which allows us to know the amount of environmental R&D investment for 22 sectors. According to the information provided by the Spanish Institute of Statistics, roughly 3% of private R&D investment was devoted each year to this environmental objective in the period 2008-2013 by the whole of Spain's industry. Although all sectors reported investing in environmental R&D, there were significant differences between them. The main investors, however, were Repair and installation of machinery and equipment (10.9% in 2013), Paper, publishing and printing (9.3% in 2013), Non-metallic mineral products (8%) and Metal products (5.5%).

In addition to the limitations affecting the dependent variable, empirical analyses in this field also face difficulties obtaining information about the explanatory variables. However, as stressed in the theoretical framework (Horbach et al., 2013), different explanatory variables, including policy instruments, need to be taken into consideration. In this paper, we build a comprehensive dataset for 22 manufacturing sectors for the period 2008–2013 from six surveys, five conducted by the Spanish Institute of Statistics and one by the International Organisation for Standardisation (ISO) (see Table 1 for descriptive statistics). They are:

a) The Technological Innovation Survey (the Spanish version of the CIS). This survey, together with the information on total internal R&D and environmental R&D, provides information about the main characteristics of the technological innovation of all firms and sectors.

b) The Industrial Companies Survey. This survey collects annual information on the main characteristics of the firms and sectors, including number of employees, sales and export figures. It also collects information on the acquisition of intermediate inputs, including those of electricity, gas and other energy products.

c) The Environmental Protection Activities Survey. This survey provides information on expenditure by firms from the industrial sectors on environmental protection including that spent on reducing or eliminating the emission of atmospheric pollutants and treating solid waste.

d) The Environmental Tax Account. This collects information on taxes whose base is associated with some material that has a proven and specific negative impact on the environment. From this survey we draw information about energy and pollution taxes by industrial sector.

e) The Air Emissions Account. This presents data about contaminating emissions into the atmosphere. From this survey we draw information about emissions of carbon dioxide by industrial sector.

f) Finally, we include information about environmental management systems. Specifically, we use ownership of an approved ISO14001, one of the most widely disseminated forms of this management system (Demirel and Kesidou, 2011; Del Río et al., 2016). Information regarding ISO14001 accreditation for Spain's manufacturing sector was provided directly by the ISO, but has only been available since 2009.

[Insert Table 1 around here]

4. RESULTS

We use a panel data set of 22 Spanish manufacturing sectors for the period 2008–2013 to study the main drivers of R&D investment. We present our main results in two tables that separate pollution prevention strategies (Table 2) from regulatory and policy measures (Table 3).

Our findings consider, first, the heterogeneity problem of different levels of R&D investment across industries and, second, the endogeneity problems associated with the reverse causality of generic subsidies or the investment in prevention measures as part of the production process. Both problems are addressed by employing a variety of methods and checked using robustness tests. The procedures employed are explained below.

We estimate a random effects model and, as we are able to confirm that some of our X variables are correlated with the unobserved firm effect, we propose modelling this unobserved firm effect explicitly using $\mu i = \lambda \bar{\mathbf{X}} I + vi$, where v is not correlated with the error term e_{it} and $\bar{\mathbf{X}}$ represents the sectoral mean of exogenous variables.

In addressing the endogeneity problem we include the above approach in our estimation, and we check the robustness of subsidies and investment in prevention measures among the production process variables in our model using several methods, including instrumental variables and the Hausman-Taylor estimator.

Our main findings can be summarised as follows. When we consider each environmental strategy in isolation, we observe that they matter as drivers of R&D investment. These positive effects coincide with the link Cohen and Levinthal (1990) identified between sources of knowledge and competition and with Kesidou and Demirel’s (2012) recognition of organisational capabilities and environmental systems as drivers of eco-innovation. We find no quantitative differences between investment in the production process and in end-of-pipe solutions; however, the role of acquisition of energy products is a more relevant factor. This implies that the weight of inputs may be crucial in a firm's R&D budget while other investments are broader and less clearly defined. In addition, environmental management systems (ISO14001) are also significant and positive as literature claims. In addition, environmental management systems (ISO14001), in line with the literature, are also significant and positive.

[Insert Table 2 around here]

When controlling for correlation using the Mundlak method, we obtain the same results in terms of magnitude. Note that in the estimation we take into account several controls, including time, and various firm controls, including foreign and human capital, demand, and technological opportunity. In these controls, only the human capital variable is relevant in terms of its effect on R&D investment. This variable is a ratio of the number of employees engaged in R&D to total employees and as such is a measure of the intensity of the effort dedicated to innovation. In the remaining results, this variable always presents a marked effect.

Our main findings regarding regulatory and policy measures are presented in Table 3. Application of the Mundlak method again reveals them to be robust and we observe that the use of (non-specific) subsidies has a greater effect on R&D investment than the use of the other regulatory instruments. It would seem it is more beneficial to provide opportunities than it is to punish. However, if punishments have to be meted out, it appears that it is preferable to use specific tools related to the environment or environmental taxes.

[Insert Table 3 around here]

In the last column of Table 3, we show the results when the estimation includes all the policy measures. These confirm our previous findings, namely, that regulatory stringency and environmental taxes are important but that subsidies are twice as important in promoting eco-innovation.

As a final exercise, we undertake several robustness checks. The first concerns the possibility that some variables, such as environmental norms and stringency, act as moderators of subsidies. To verify this, we estimate several interactions but none of them produce significant results. In a second step, and in order to test the robustness of the model, we sought to replicate the same model but using internal R&D as our dependent variable and leaving environmental expenses out of the estimation. The results in this case confirm the expectations that some determinants are specific to environmental R&D. In this estimation for non-environmental R&D, public support continues to be significant and positive but pollution taxes are not significant and the parameter for energy taxes is significant and negative. A further result worth highlighting is that human capital is no longer relevant but the participation of foreign capital is in the development of R&D investment.

Finally, we examined the endogeneity problem identified earlier by considering two variables that might be responsible for this problem: namely, subsidies and investment in the production process. In the following, we describe the several steps employed. First, we substitute these variables with their respective lags to detect the possible time causality. Second, we use the IV method considering as our instrument the lags of the variables. Third, we apply the Hausman-Taylor method. The difference between these two methods lies in the respective assumptions they make about the correlation with the error term. The estimators implemented using the IV method assume that a subset of the explanatory variables in the model are correlated with the idiosyncratic error e_{it}. In contrast, the Hausman-Taylor and Amemiya-MaCurdy estimators assume that some of the explanatory variables are correlated with the individual-level random effects, but that none of the explanatory variables are correlated with the idiosyncratic error. Our results are reported in Table 4.

[Insert Table 4 around here]

Our findings seem to suggest that investment in the production process, in contrast to subsidies, is not correlated with the unobserved fixed effect. This means that some reverse causality between the application of subsidies and investment in environmental R&D exists leading to policy implications.

5. CONCLUSIONS

This paper has sought to contribute to the empirical literature examining the drivers of environmental innovation. Indeed, there is considerable interest in identifying the determinants of eco-innovation given that environmental technological advances are essential to face the challenges posed by climate change.

This paper has focused its attention specifically on the determinants of environmental R&D. Although R&D is one of the main variables considered when analysing the economics of innovation, data constraints substantially limit empirical analyses of investment in environmental R&D. To examine these determinants, therefore, we have compiled a database with information taken from different sources concerning innovation, economic and environmental activities and the characteristics of firms and sectors. In addition, we have included all information available on policy instruments designed to promote environmental R&D.

In line with the literature, we have adopted a simple framework for separating the determinants of eco-innovation: namely, firm strategies, technology, market and regulations. Using this framework, we have formulated several hypotheses regarding the impact of firms' strategies and policy instruments on investment in environmental R&D.

To test these hypotheses, we have carried out an empirical analysis with panel data for 22 manufacturing sectors in Spain for the period 2008–2013. In conducting this analysis we have taken into account various concerns regarding the heterogeneity of R&D investment across industries and potential endogeneity attributable to the reverse causality of some of the variables. The empirical analysis confirms the existence of distinctive features in relation to the drivers of investment in eco-innovation.

First, we find a positive relationship between investment to prevent pollution and R&D efforts. This result holds for both types of investment, that is, investment in the production process and in end-of-pipe solutions. We also find a positive relationship between the greater use of energy products as an intermediate input in the production process and investment in environmental R&D.

Second, instruments of innovation policy as well of environmental policy have a positive impact on levels of investment in environmental R&D. The results show that R&D subsidies have a significant impact on promoting R&D specifically devoted to environmental concerns. The empirical analysis also shows that specific environmental taxes that target pollution and the use of resources also have a positive effect on environmental R&D. However, the same does not hold true for general energy taxes. Finally, the stringency of regulations has a positive effect on levels of environmental R&D.

All in all, these results show that public policies are essential in promoting environmental R&D. Moreover, in line with the literature, they show the positive effects of combining innovation policy instruments, such as R&D subsidies, with environmental policy measures, such as taxes and stringent regulations.

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Table 1. Descriptive Statistics

	Obs.	Mean	Std. Dev.	Min	Max
Environmental R&D (in logs)	138	5.622	9.796	0	775.96
Sales (in logs)	138	18.417	1.221	16.112	20.937
Human RD personnel intensity	138	3.634	3.797	0.520	13.829
Foreign capital	137	24.445	23.704	1	98
Log of investment in production process	132	15.129	1.951	9.375	18.201
Log of investment in end-of-pipe	131	14.945	2.213	7.850	18.596
Log of acquisition of energy products	138	12.521	1.239	10.486	14.731
Importance to reduce environmental impact	138	25.544	14.406	2.7	100
Log of energy taxes	90	10.777	1.128	8.160	13.411
Log of pollution taxes	60	7.797	1.712	4.605	10.211
Log of CO2 emissions	90	7.132	1.863	3.114	10.648
Log of ISO14001	80	5.389	1.152	2.565	7.046

Table 2. Effect of Environmental Strategies on Pollution Prevention

	Random effects				RE-Mundlak				
	Invest in the prod. process	**Invest end-of-pipe**	**Acq. of energy products**	**EMS**	**Invest in the prod. process**	**Invest end-of-pipe**	**Acq. of energy products**	**EMS**	**TOTAL**
Investment prod. process	0.258*** (0.082)				0.248*** (0.086)				-0.194 (0.144)
Investment end-of-pipe		0.250*** (0.076)				0.239*** (0.083)			0.022 (0.142)
Acquisition energy products			0.799*** (0.187)				0.743*** (0.195)		0.902*** (0.373)
ISO14001				0.476*** (0.187)				0.683*** (0.161)	0.128 (0.260)
CONTROLS									
Constant	8.203*** (3.262)	7.596*** (3.427)	-1.722 (4.424)	4.077 (3.504)	8.826*** (3.913)	8.051** (3.887)	-1.152 (4.982)	0.855 (2.765)	-7.676 (4.719)
Log Sales	-0.035 (0.178)	0.007 (0.176)	0.182 (0.181)	0.300 (0.189)	0.199 (0.413)	0.133 (0.401)	0.290 (0.389)	-0.699 (0.543)	-0.514 (0.547)
Human RD intensity	0.148*** (0.060)	0.162*** (0.060)	0.190*** (0.061)	0.076 (0.076)	0.559*** (0.188)	0.754*** (0.187)	0.544*** (0.175)	0.804*** (0.319)	0.780*** (0.327)
Foreign capital	-0.699 (1.606)	-0.479 (1.547)	-1.477 (1.515)	-0.119 (1.340)	-0.095 (1.727)	0.091 (1.642)	-0.339 (1.651)	0.522 (1.457)	-0.260 (1.403)
Importance to reduce env. impact	0.008 (0.013)	0.003 (0.012)	0.006 (0.012)	0.011 (0.011)	-0.007 (0.017)	-0.007 (0.016)	-0.011 (0.016)	-0.004 (0.013)	-0.003 (0.015)
M(Human RD)					-0.447*** (0.199)	-0.654*** (0.198)	-0.377** (0.188)	- 0.806*** (0.332)	-0.665** (0.347)
M(Foreign)					-0.263 (4.304)	0.735 (4.103)	-3.075 (3.982)	0.485 (3.826)	4.901 (4.655)
M(Reduce env. Impact)					0.026 (0.027)	0.011 (0.027)	0.038 (0.025)	0.037* (0.021)	0.049** (0.025)
M(lsales)					-0.261 (0.461)	-0.123 (0.454)	-0.106 (0.442)	1.084** (0567)	1.044** (0.565)
N. observations	130	129	136	80	130	129	136	80	75

Table 3. Effect of Regulation and Policy Measures

	Random effects				RE-Mundlak				
	Public Funds	**Energy taxes**	**Env. Taxes**	**Stringency**	**Public Funds**	**Energy taxes**	**Env. Taxes**	**Stringency**	**TOTAL**
Subsidies	0.613*** (0.116)				0.746*** (0.111)				0.486*** (0.140)
Energy Tax		0.331 (0.254)				0.365 (0.305)			-0.382 (0.272)
Pollution Tax			0.283*** (0.127)				0.304* (0.179)		0.187*** (0.092)
CO2				0.396*** (0.145)				0.393*** (0.142)	0.221* (0.132)
CONTROLS									
Constant	5.583* (2.974)	3.579 (4.183)	11.19*** (3.314)	3.331 (3.624)	4.555 (2.973)	5.731 (4.673)	11.26** (5.614)	3.126 (4.011)	5.345*** (2.495)
Log sales	0.032 (0.151)	0.285 (0.216)	0.034 (0.187)	0.336* (0.196)	0.516 (0.377)	0.498 (0.357)	0.031 (0.422)	0.525 (0.353)	0.224 (0.531)
Human RD intensity	-0.034 (0.057)	0.087 (0.078)	0.374*** (0.122)	0.119* (0.070)	0.550*** (0.170)	0.612*** (0.185)	0.381 (0.318)	0.631*** (0.184)	0.182 (0.382)
Foreign capital	0.084 (1.470)	-1.008 (1.275)	0.753 (1.148)	-0.729 (1.213)	2.036 (1.609)	0.116 (1.317)	0.608 (1.264)	0.234 (1.299)	1.071 (1.700)
Importance to reduce env. impact	0.023*** (0.011)	0.003 (0.014)	-0.006 (0.011)	-0.002 (0.013)	-0.016 (0.015)	-0.005 (0.017)	0.003 (0.017)	-0.004 (0.017)	0.009 (0.022)
M(Human RD)					-0.628*** (0.181)	-0.551*** (0.204)	-0.003 (0.355)	-0.550*** (0.194)	-0.031 (0.380)
M(Foreign)					-4.316 (3.238)	-4.407 (4.652)	-0.040 (5.371)	-3.010 (3.548)	-0.624 (2.371)
M(Reduce env. impact)					0.068*** (0.021)	0.011 (0.028)	-0.016 (0.032)	-0.001 (0.025)	-0.002 (0.025)
M(lsales)					-0.498 (0.406)	-0.174 (0.443)	0.010) (0.508)	-0.133 (0.416)	-0.036 (0.537)
N observations	136	89	60	89	136	89	60	89	60

Table 4. Robustness Diagnostics

	IV	Hausman - Taylor	IV	Hausman - Taylor	
Dependent Variable	**Log of Environment R&D investments**				**Log of R&D Investments**
Investment in production process	0.473*** (0.124)	0.120 (0.096)			
Subsidies			1.072*** (0.139)	0.564*** (0.143)	0.892*** (0.090)
Energy Tax					-0.286*** (0.114)
Pollution Tax					0.014 (0.039)
CO2					0081* (0.055)
CONTROLS					
Constant	4.615 (3.463)	11.206*** (4.720)	1.433 (2.593)	6.427** (3.577)	0.152 (1.151)
Log Sales	0.083 (0.572)	0.279 (0.400)	0.547 (0.522)	0.479 (0.369)	-0.001 (0.223)
Human RD intensity	0.379 (0.282)	0.531*** (0.183)	0.576*** (0.258)	0.538*** (0.167)	0.213 (0.161)
Foreign capital	-0.086 (2.043)	0.103 (1.671)	2.701 (1.896)	1.634 (1.587)	2.401*** (0.713)
Importance to reduce env. impact	-0.012 (0.020)	-0.006 (0.016)	-0.019 (0.018)	-0.014 (0.015)	-0.004 (0.009)
M(Human RD)	-0.251 (0.291)	-0.426*** (0.199)	-0.736*** (0.272)	-0.574*** (0.183)	-0.164 (0.159)
M(Foreign)	-2.797 (3.905)	1.110 (5.082)	-6.027** (3.063)	-3.369 (3.708)	-0.575 (0.994)
M(Reduce env. impact)	0.025 (0.026)	0.028 (0.131)	0.075*** (0.022)	0.063*** (0.024)	0.016* (0.010)
M(lsales)	-0.094 (0.599)	-0.374 (0.472)	-0.474 (0.541)	-0.480 (0.410)	0.160 (0.225)
N observations	108	130	113	136	60
Instruments:	$Lprevec_{t-1}$		$Lfunds_{t-1}$		
Rho	0.375	0.719	0.302	0.616	
Σ_u	0.627	1.084	0.476	0.813	
σ_e	0.809	0.677	0.725	0.643	0.093

2012

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