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. In addition, this paper 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. The main implications from our results are 1). Managerial strategy appears as a relevant driver of environmental R&D investments. 2) The establishment of a policy mix between environmental, energy and technological regulatory measures is recommended. 3) The promotion of self-regulation through actions that encourage companies to follow a policy that affects their energy efficiency and is environmentally friendly.

Key words: Environmental innovation, tax and demand instruments, panel data.

JEL: O30, Q50, Q58

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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. 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.

Resource-based theory highlights the importance of using internal capabilities and resources to maintain the sustainability of competitive advantage (Chen 2008, Leonidou 2013). These resources entail human knowledge, information technology and capital. Investment in these resources will necessarily lead to greater environmental efforts. 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). 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. Stakeholders (internal and external) usually exert influence on managers to adopt accreditations or certifications as a way to improve reputations and therefore performance. Here, the introduction of different levels of EMS can act as one of several facilitator factors in both the development and adoption stages of eco-innovation. Among the EMS certifications (ISO 14001, ISO 9001 and EMAS), only ISO 14001 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. (2012) 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). Moreover, regulatory measures also help to alleviate the double externality phenomenon. 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, we take into account time-invariant characteristics through random effects μ_i and time effects using time dummies to control for business cycle effects common to all industries.

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 (INE) and one by the International Organisation for Standardisation (ISO) (see Table 1 and Table A.1 for general and industry-level descriptive statistics respectively and Table A.2 for the definitions of the variables and the sources). They are:

a) Innovation in Companies 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 firms and sectors. Since 2002 the Innovation in Companies Survey has been carried out in Spain annually in coordination with the Statistics on R&D activities survey with a single questionnaire for the firms. The sample of approximately of 40,000 firms includes companies that can potentially develop R&D activities, companies with over 200 employees and a random section drawn from the Central Company Directory (CCD). In our database we have used the information published by the Spanish Institute of Statistics for industrial sectors. The information of this survey has been frequently used to carry out empirical analysis on R&D and innovation (see, among others, De Marchi, 2012; Segarra and Teruel, 2014; Marzucci and Montresor, 2017).

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 ISO 14001 that, as pointed by Kesidou and Demirel 2002 and Testa et al. (2014), is one of the most widely disseminated forms of environmental management system together with the Eco Management and Audit Scheme (EMAS). The ISO 14001 can be used by any firm, regardless of its activity, that aims to set up an environmental management system and obtain a certification for their productive process. ISO 14001 has been frequently used in empirical analysis on the drivers of eco-innovations as two recent reviews of the literature show (Del Río et al., 2016; Hojnik and Ruzzier, 2015). It has also been found that it is effective in stimulating environmental R&D (Demirel and Kesidou, 2011). Information regarding ISO 14001 accreditation for Spain's manufacturing sector was provided directly by the International Organisation for Standardisation, 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). In table 2, we try to answer the hypotheses H1 while in table 3 we report the findings of our hypotheses H2-H4.

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 $\mu i = \lambda \overline{X} I + vi$, where v is not correlated with the error term e_{it} and $\overline{X}$ 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, confirming our hypotheses H1a-H1d. 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 (ISO 14001) are also significant and positive as literature claims. Since the EMS is a worldwide tool potentially applicable by any kind of organization in order to improve the management of its environmental performance (Testa et al., 2014), stakeholders will push for investment to improve performance, as well. This is a way of introducing self-regulation since proactiveness in being greener could be a strategy in the decision making of managers.

These results inform us about our hypotheses that firm's strategies produce increases in investment in environmental R&D. In particular, the combination of inputs acquisition and the adoption of EMS allow companies to place emphasis on the first phase of eco-innovation: the development/innovation stage.

[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. It also underlines the importance of human resources as resource-based theory claims.

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, confirming H4. 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. Hence, regulatory pressures play an important role in alleviating the dual-externality problem.

[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. Our hypotheses about the importance of direct support are confirmed with this result. As Yang and Oppenheimer (2007) pointed out the use of subsidies complements the pollution specific action.

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. With these estimations we confirm that there are significant differences between the drivers of environmental R&D investment and those of general, non-environmental, R&D and that it is necessary to make an effort to identify the specific drivers of eco-innovation. In addition, to enhance environmental R&D requires the development of tangible and intangible resources (Sarkis et al., 2010).

The results of the estimations on policy instruments (R&D subsidies and taxes) comparing R&D innovation and R&D in general suggest that to confront the double externality problem of environmental innovation more than one instrument is required. Our estimations show that R&D subsidies and pollution taxes have a positive effect on environmental innovation while pollution taxes are not significant for non-environmental R&D. Unfortunately there is no available information on specific subsidies to environmental R&D projects that would allow a more precise analysis of policy instruments and a more detailed exploration of how to deal with the double externality of environmental innovation.

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. These results on the use of subsidies as an incentive to environmental investment suggest that government support is focused on the intensive margin. That means to those firms that undertake R&D activities on a continuous basis. These R&D subsidies are direct aid that public agencies grant to the screened companies that win R&D projects in competitive calls.

5. CONCLUSIONS AND POLICY IMPLICATIONS

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. Managerial strategy appears as a relevant driver of environmental R&D investments.

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. The results of the estimations on policy instruments comparing environmental R&D with the drivers of total R&D expenditure, where pollution taxes are not significant, suggest that more than one instrument is required to deal with the double externality problem of environmental innovation. As the literature points out (Popp et al., 2010) environmental and technology policies are more effective when they operate in tandem.

All in all, the results underscore the importance of environmental R&D investment to achieve the goal of climate change mitigation. What this requires is a combination and mix of energy policies, the promotion of R&D, regulatory and fiscal policies all which complement one another, and the promotion of self-regulation and dissemination of information.

The policy of promoting environmental R&D investment reduces technological and market uncertainty of innovative companies, on the one hand, and on the other drives the demand for innovation that encourages users to adopt the use of environmentally-friendly technology.

Given that environmental innovations are affected by the problem of double externality, implementation of environmental regulation to help foster innovation, in addition to traditional policies, becomes necessary. In this sense, a first aspect to be highlighted is the need for integration between environmental and energy measures and those designed to foster innovation. Therefore, the establishment of a policy mix between environmental, energy and technological regulatory measures is recommended, given the interconnectedness of developing environmental innovations (Crespi et al., 2015).

A second aspect is that the policy should be part of the energy policy and a third aspect is that it should encourage self-regulation, the consolidation of which is crucial in reaching the goal of climate change mitigation.

Implementation of this policy requires a broad range of instruments whose design must be based on a common goal which is to improve the environment. One might distinguish six types of measures. First, incentives in the form of subsidies to promote environmental R&D investment, including improvements in energy use. Second, market-based instruments such as the European Union Emissions Trading System. Third, environmental taxes and fees. Fourth, management and control measures such as standards setting, requiring companies to comply with environmental standards both in their production processes and products and their suppliers. Fifth, the promotion of self-regulation through actions that encourage companies to follow a policy that affects their energy efficiency and is environmentally friendly. Self-regulation, individually or agreed upon by a group of enterprises, is essential to achieving the objectives of environmental control. And sixth and last, the above measures should be accompanied by information and awareness programs.

To sum up, according to the results obtained environmental policy is fundamental in mitigating climate change. Therefore countries must treat it as a strategic policy. In addition, it has a transversal (affects all sectors and all phases of the production process) and also a mixed character (includes all kinds of instruments), especially if its purpose is to enhance environmental R&D (Quitzow, 2015).

Environmental policy requires a portfolio of instruments. As our results show the use of subsides to R&D, investment incentives to environmentally beneficial technologies and pollution taxes are the right tools to foster environmental R&D. These tools for intervention can also have positive effects both on production processes and end-of pipe investments. It is also necessary to focus on the development of intangible assets. These policies can help the development of managerial capabilities that allow opportunities to be identified in the environmental performance of companies.

These actions should be part of a stringent regulation that promotes environmental innovation among companies. A regulation in favor of environmental R&D can provide competitive advantages, according to the work of Porter and Van der Linde (1995). The opportunity to be a market leaded could be afforded by stringent environmental regulations (Beisse and Rennings, 2005). These regulations may be seen as policy measures to encourage self-regulation, since they incentivize companies to comply with them, and even surpass them, to achieve greater benefits. However, some limits exist to the stringency of environmental regulation that, if surpassed, can turn this opportunity into a problem (relocation or regulatory distance with other markets) (Antonietti et al., 2016; Dechelezpetre et al., 2015). Therefore, as in the case of seeking an optimal combination of policy tools to promote environmental innovation, an optimal level of environmental regulation is also required.

The application of a portfolio of policies for the promotion of environmental R&D also generates expectations in stakeholders that reinforce its effect. In this way, if environmental innovation promotion exists, investors are more attracted to this type of investment, while penalizing the allocation of resources towards more polluting technologies. Therefore, the companies themselves are motivated to develop environmental R&D to attract new sources of funding or maintain the existing ones. Environmental regulation and economic instruments for the promotion of environmental R&D can be considered as elements that favor self-regulation by companies.

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Table 1. Descriptive Statistics

	Obs.	Mean	Std. Dev.	Min	Max
Environmental R&D (in logs)	138	12.210	1.491	7.015	14.684
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	.114	0.095	.007	.667
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 subsidies	138	8.799	1.484	3.178	12.211
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

ANNEX.

TABLE A.1. DESCRIPTIVE STATISTICS BY INDUSTRY

Division (Manufacture)		Environmental R&D	Log of Investment in prod process	Log of investment in end-of-pipe	Log of Subsidies	Log of Acq.. energy products	Log of energy taxes	Log of Pollution tax	Log of CO2 emissions	Log of ISO14001
		lgenv	ltratc	lprevc	lfunds	ladqpe	limpen	limpcrn	lco2	LISO14001
Mining and Quarrying (CNAE 05, 06, 07, 08, 09)	Mean	12.08039	15.25677	16.58808	7.064843	12.94175	11.39536	9.776195	8.144914	4.682436
	S.D	0.412655	0.423075	0.7210219	1.289877	0.0807106	0.2027653	0.3857375	0.3067248	0.0614839
Food, beverages and tobacco products (CNAE 10, 11, 12)	Mean	13.17706	17.77701	17.45167	10.10737	14.61252	12.07144	9.583046	8.57816	6.661897
	S.D	0.1607555	0.180851	0.4161457	0.2646669	0.0967118	0.0363557	0.3274098	0.0455154	0.1354946
Textiles (CNAE 13)		11.12437	13.06516	14.33141	8.290161	12.30343	3.188543* 0.1659827	3.093098* 0.1989132	6.360258* 0.0664117	4.48063* 0.3251505
		0.3626502	1.549448	0.8744258	0.4924095	0.0426809				
Wearing apparel (CNAE 14)	Mean	8.518127	9.777922	10.56094	6.376417	10.90586				
	S.D	2.030922	1.918227	1.003625	1.599031	0.1764128				
Leather and related product (CNAE 15)		10.58244	13.28982	12.67526	6.913089	10.85892				3.383358
		1.466575	0.430597	0.6817836	0.7568609	0.1284805				0.2906951
Wood and of products of wood and cork (CNAE 16)	Mean	9.996566	14.2811	14.05089	7.372109	12.49167	10.4466	4.963522	6.523273	4.951707
	S.D	1.019962	1.247445	1.26094	0.2872668	0.0807903	0.1665985	0.5112049	0.0594123	0.0830106
Paper and paper products, Printing and reproduction of recorded media (CNAE 17- 18)	Mean	12.61	12.61	12.61	12.61	12.61	12.61	12.61	12.61	6.042333
	S.D	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	0.117739
Coke and refined petroleum products (CNAE 19)	Mean	12.50685	18.31419	17.42093	7.764865	12.81993	13.15506	8.985047	9.685541	3.048275
	S.D	0.1793831	0.1570783	0.2765784	0.6444038	0.3831499	0.1880609	0.3111324	0.0463505	0.3027128
Chemicals and chemical products (CNAE 20)	Mean	14.0311	17.63883	17.59881	9.71376	14.29883	11.45547	9.323435	8.914592	6.390927
	S.D	0.1247197	0.3500376	0.262829	0.320496	0.1347729	0.1082172	0.3104618	0.052968	0.176693
Basic pharmaceutical products and pharmaceutical preparations (CNAE 21)	Mean	11.48223	15.74799	15.94756	9.767017	11.91334	10.02105	0	3.338272	4.110952
	S.D	0.4553958	0.2999834	0.2803137	0.2535548	0.1102054	0.0858916	0	0.181151	0.1850528
Rubber and plastic products (CNAE 22)	Mean	13.0788	16.74853	15.53952	9.315876	13.25872	11.5089	6.847772	6.566814	5.901057
	S.D	0.1367704	0.2398903	0.6932351	0.2834855	0.0409732	0.071793	0.3897748	0.071864	0.1346154
Other non-metallic mineral products (CNAE 23)	Mean	13.1301	17.40936	16.41807	8.809146	14.38527	11.10281	7.697777	10.38753	5.825871
	S.D	0.2517128	0.5621892	1.31391	0.4985355	0.1555694	0.232286	0.3635794	0.1637158	0.1126027

Basic metals (CNAE 24)	Mean	12.60724	17.0215	17.53507	9.27211	14.38418	11.68203	8.565221	9.385687	
	S.D	0.3505099	0.6700175	0.4411209	0.3559253	0.0538688	0.1395025	0.3168831	0.0792614	6.927365*
Fabricated metal products, except machinery and equipment (CNAE 25)	Mean	12.47116	15.48421	15.90794	9.743268	13.36432	10.95082	0	6.921757	0.0823018
	S.D	0.3939446	1.011297	0.5061088	0.4154086	0.0759348	0.1338505	0	0.0637574	
Computer, electronic, and optical products (CNAE 26)	Mean	12.50108	12.66136	13.25528	10.27998	10.63004	8.462883	0	4.868401	
	S.D	0.1864332	0.8770544	0.9646092	0.3691578	0.1496987	0.2141272	0	0.1533109	6.280338*
Electrical equipment (CNAE 27)	Mean	13.33338	14.23526	15.70901	9.764332	12.02022	10.58122	6.038578	6.49611	0.0746493
	S.D	0.7982319	0.439076	0.673394	0.3442088	0.052555	0.0450498	0.3475729	0.1280055	
Machinery and equipment n.e.c. (CNAE 28)	Mean	13.06659	15.02121	14.4925	10.18035	12.08994	10.5406	5.132982	6.574629	6.395357
	S.D	0.366482	0.6174741	1.172316	0.3680626	0.0591592	0.0950146	0.8476577	0.147046	0.1378229
Motor vehicles, trailers and semi-trailers (CNAE 29)	Mean	13.33936	15.03134	16.79294	9.979488	12.96703	11.16923	7.395905	7.270286	
	S.D	0.9450325	0.8795857	0.6292211	0.5006133	0.0826277	0.0933435	0.3736554	0.0802471	5.790369*
Other transport equipment (CNAE 30)	Mean	13.75005	14.31521	14.86456	12.05294	11.37456	9.361152	0	5.839557	0.2613724
	S.D	1.181771	0.6093658	0.43551	0.1221385	0.0748524	0.2071129	0	0.1392171	
Furniture (CNAE 31)	Mean	11.22829	13.30584	13.93749	7.232455	11.79047				
	S.D	0.3066844	1.094522	1.602942	0.4150327	0.151354	3.032443*	3.00712*	4.830277*	5.362318*
Other manufacturing activities (CNAE 32)	Mean	10.44137	12.11526	13.82038	8.510214	10.75165	0.1531099	0.1624053	0.2324247	0.2455441
	S.D	0.630669	0.8092662	0.8751639	0.4651875	0.07843				
Repair and installation of machinery and equipment (CNAE 33)	Mean	11.31764	12.86406	13.30159	7.756545	11.16389	8.732975	0	4.030899	
	S.D	0.5340272	0.6748466	1.034011	0.5974804	0.1715559	0.0802142	0	0.1817937	
Sewerage , Waste collection, treatment and disposal activities; materials recovery and Remediation activities and other waste management services (CNAE 37, 38, 39)	Mean	14.01708	NA	NA	8.40235	12.82014	10.33948	0	6.868012	
	S.D	0.3783091	NA	NA	0.7532174	0.2728018	0.0854876	0	0.0615154	

*Information only available aggregated for the whole sector

Table A.2. The variables: definitions and sources

Variables	Definitions	Source
Environmental R&D	Business R&D expenditure on the control and care of the environment	Statistics on R&D activities and Innovation in Companies Survey, National Statistics Institute of Spain (INE)
Sales	Annual Turnover	Industrial Companies Survey, INE
Human R&D personnel intensity	Personnel in R&D as % of total personnel	Statistics on R&D activities and Innovation in Companies Survey, INE
Foreign capital	Number of firms with more than 50% of foreign capital as % of total firms	Statistics on R&D activities and Innovation in Companies Survey, INE
Subsidies	Public subsidies to R&D activities of the firms	Statistics on R&D activities and Innovation in Companies Survey, INE
Investment in the production process	Investment in environmental protection (integrated equipment and facilities)	Environmental protection activities survey, INE
Investment in end-of-pipe	Investment in environmental protection (independent equipment and facilities)	Environmental protection activities survey, INE
Acquisition of energy products	Expenditure on acquisition of energy products (electricity, gas and other fuels)	Industrial Companies Survey, INE
Importance to reduce environmental impact	Firms that consider of high importance the innovation objective “Reduce environmental impact” (as % of total firms)	Innovation in Companies Survey, INE
Energy taxes	Taxes on energy	Environmental tax account, INE
Pollution taxes	Taxes on pollution and resources	Environmental tax account, INE
CO2 emissions	Carbon dioxide emissions into the atmosphere of (thousands of tonnes of equivalent CO2)	Air emissions account, INE
ISO14001	Number of ISO 14001 certifications per industry	International Organization for Standardization

Note: Information at industry level. 22 manufacturing sectors, period 2008-2013, Spain