How R&D cooperation, R&D expenditures, public funds and R&D intensity affect green innovation?

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Abstract

Green innovation plays a substantial role in creating new products and services, as well as in reducing environmental impacts and promoting the efficient use of resources and materials. This study investigates the linkage between green innovation and research and development (R&D) practices inside and outside firms over time; it also explores types of external partners. The results show that internal and external R&D efforts enhance the activities of green innovation. However, the external partner is an important factor, whereas cooperation with competitors could help firms in general affairs not related to competition.

Keywords: green innovation; R&D cooperation; R&D expenditures; public funds; R&D intensity.

1. Introduction

Most organizations all over the world are paying more attention to environmental issues (Angelo et al., 2012); the Europe 2020 strategy, in particular, is devoted to green innovation by supporting firm initiatives (Cecere et al., 2020) to develop environment-friendly products and sustainability (Xie et al.,

2019) by enhancing resource efficiency, saving raw materials and decreasing pollution (Cai and Li, 2018).

Technological capabilities, market demand and regulations are the most influential factors in green innovation (Horbach, 2008; Del Río et al., 2015). Green technology capabilities consist of infrastructure and knowledge capital (Horbach, 2008). They play a crucial role in preventing or eliminating environmental impact and achieving ecological improvement (Song et al., 2019) in order to promote productivity and attain equilibrium between the costs and benefits of green innovation (Chen et al., 2006).

In this manner, green innovation occurs in many phases, starting with innovation activities and ending with patents and products or services (Gopalakrishnan and Damanpour, 1997). This may require building external relationships that promote the R&D practices and human resources development that in turn promote green activities and protect the environment (Rezende et al., 2019).

Firms need to strengthen their networks of external partners or else they may struggle to develop internal knowledge and capabilities without external collaboration (Doloreux et al., 2018). Resource-based theory suggests that firms with distinguished resources require partners and supporters to create superior products and efficient processes (Das and Teng, 2000). However, customer reaction to green innovation is a possible obstacle if green products cost more than nongreen products (Arranz et al., 2019). In this context, regulatory factors motivate innovation (Porter and van der Linde, 1995). These factors have several aspects: government pressure, pressure from customers, pressure from nongovernmental organizations (NGOs) and competition pressure (Berrone et al., 2013).

Therefore, this research provides a better understanding of the relationship between internal and external R&D practices and green innovation. The research questions include whether R&D cooperation relates to green innovation in Spanish firms, and if so, how the patterns of R&D cooperation differ and how much R&D expenditures affect green innovation. Therefore, this paper's contribution is a deeper comprehension of how internal and external R&D practices, including firm size as a control variable, affect green innovation. The paper structure is as follows: section 2 presents the background literature and proposes the hypotheses; section 3 describes the data, method and methodology; section 4 discusses the results; and section 5 provides conclusions and identifies future lines of research.

2. Literature review and hypothesis

2.1. Green innovation

Literature uses various idioms for green innovation, such as "eco-innovation," "environmental innovation" and "sustainable innovation" (Rezende et al., 2019; De Marchi, 2012). Despite their differences, they all encompass products or process innovations that save energy and materials, minimize or stop pollution, increase recycling and improve the regulatory environment (Chen et al., 2006). They also provide competitive advantages and sustainability (Pujari, 2006).

In this way, most authors classify green innovation activities into green product innovation and green process innovation categories. Green product innovation includes environmental improvements, recycling, reductions in raw materials and selection of raw materials (Chen et al., 2006; Xie et al., 2019); green process innovation minimizes energy consumption and increases resource efficiency (Xie et al., 2019).

In this context, reinforcing material and energy efficiency relies on developing technological and innovation capabilities that work with high market uncertainties and technological changes (Del Río et al., 2015) Therefore, introducing green innovation requires introducing internal green practices such as environmental policies and innovations that reduce production costs, enhance operating and administrative efficiency, and improve firm performance (García-Marco et al., 2020).

2.2. R&D cooperation with external partners and green innovation

Many theoretical and empirical studies reveal that cooperation with external partners is an essential driver of green innovation (De Marchi, 2012; Horbach, 2016; Arranz et al., 2019). R&D cooperation in particular provides opportunities to access knowledge, acquire skills, and acquire advanced technology (Arranz et al., 2019), as well as share uncertainty and the cost of innovation (Souto and Rodriguez, 2015). This is consistent with social-network theory, which states that building strong relationships is fundamental to sharing knowledge (Tsai, 2002).

Accordingly, firms can benefit from knowledge spillovers, as advanced research, experience, qualified human resources and innovative ideas come from research centers or universities (Díez-Vial and Fernández-Olmos, 2015). In this vein, Sánchez-Sellero et al. (2015) state that if a firm conducts a higher number of activities related to internal organization or external collaboration for innovation, it becomes more productive. R&D cooperation with partners includes equipment and materials suppliers, customers, universities, technology labs, competitors, peer firms, consultants and others (De Marchi, 2012; Arranz et al., 2019).

In this way, collaboration with suppliers plays an essential role in material use, production processes and environmental impacts in manufacturing facilities (Geffen and Rothenberg, 2000). De Marchi (2012) confirm that building relationships with suppliers helps companies acquire and exchange information via material use, operations, processes, and environmental impacts. Furthermore, establishing efficient green practices with suppliers helps develop decision-making and resource use (Fernando et al., 2019). Also, Pennacchio et al. (2018) find that establishing networks with suppliers is the best strategic way to attain the highest benefits of innovative performance. It also contributes to a relatively broad range of competitive benefits in the scope of green practices (Vachon and Klassen, 2008). Consequently, new product innovation involves adopting green activities (De Marchi, 2012).

International laws allow competitors to cooperate in R&D as long as there is competition (Amir et al., 2003). In this area, Horbach (2016) and Marzucchi and Montresor (2017) study the importance of competitors as a source of information about green activities and the formation of win-win situations in which both competitors come out on top. Nonetheless, cooperation with competitors may only happen in firms with highly effective protection strategies to share knowledge with competitors (López, 2008), which reduces investments in preserving knowledge and patents (Amir et al., 2003). This can lead to a trade-off between competitive advantages and the benefits of shared costs and risk reduction (Pennacchio et al., 2018). In this regard, Tether (2002) finds that cooperation among competitors may help solve general problems in areas not related to firms' core businesses. Which can be more influence only concerning the organizational innovations and common practices beyond the competition area among the rivals (Pennacchio et al., 2018). Accordingly, we state the following hypotheses:

Hypothesis 1 (H1): R&D cooperation with suppliers increases green innovation activities.

Hypothesis 2 (H2): R&D cooperation with competitors increases green innovation activities beyond the competition area.

2.3. Public funds and green innovation

Public R&D financing could be internal or external. Internal financing includes share capital, reserves, and assets; external financing includes grants from government R&D subsidies, as well as national and international institutions, joint ventures and loans (OECD and EUROSTAT, 2005). However, firms often have to pay the costs of green innovation practices without receiving returns on those environmental investments. Therefore, the balance between economic value and environmental matters may prompt green innovations (Jin and Huang, 2014). This situation could have negative externalities.

However, knowledge spillover is a positive externality of green innovation (De Marchi, 2012). The negative externality requires appropriate environmental regulations that stimulate green innovation activities. The positive externality of technology innovation needs guidance and support from the government through funding policies (Porter and van der Linde, 1995; Guo et al. 2018). In such manner, Liu and Rammer (2016) assert that public financial support positively affects product and process innovations, and they classify public funds into three sources: national, regional and European.

Local governments undoubtedly play a vital role in formulating appropriate regulations and policies, as well as providing subsidies to develop green economies and deal with financial crises (Souto and Rodriguez, 2015). The influence of government subsidies on green innovation takes various forms, including direct funding for firms' green activities, tax incentives and training for R&D staff (Guo et al., 2018). Furthermore, providing direction for green R&D reduces risks related to green innovation and encourages firms to apply green innovation amid stringent regulations (Květoň and Horák, 2018).

Overall, public funding has a higher impact on R&D activities. The importance of public R&D funding stems from environmental innovation, risk and uncertainty in market demand. These factors play a pivotal role in public funding and thus improve the capacity of green innovation activities (Souto and Rodriguez, 2015; Arranz et al., 2019) and the number of patents (Plank and Doblinger, 2018). This leads to the following hypothesis:

Hypothesis 3 (H3): Public funds have a positive relationship with green innovation activities.

2.4. R&D expenditures and green innovation

Many studies find that R&D expenditures play a crucial role in creating new eco-friendly products and technologies, as well as in enhancing green innovation. Fujii and Managi (2019) highlight the significance of green applications through the number of green patents and R&D expenditures as a proportion of GDP, which increase firm productivity (Sánchez-Sellero et al., 2015) and create conditions for innovation (Rosell-Martínez and Sánchez-Sellero, 2012).

Notwithstanding, environmental R&D expenditures can increase operating costs, consequentially reducing profits and negatively affecting financial performance (Sueyoshi and Goto, 2009). However, environmental R&D expenditures may also create competitive advantages by helping firms absorb knowledge spillovers from outside sources (Sánchez-Sellero et al., 2014a) and enhancing the capacity to handle environmental issues (Kim and Kim, 2018).

Choosing between internal and external R&D depends on firm assets, the level of technology in the industry and whether firms compete in sectors with high technology (Audretsch et al., 1996). In this context, Jové-Llopis and Segarra-Blasco (2018) highlight the importance of internal and external R&D efforts as a main source of knowledge, and they find a positive and significant influence on the capability of Spanish firms to adopt green innovation. This is due to the need for advanced technologies and clean energy. We thus propose the following hypotheses:

Hypothesis 4 (H4): Internal R&D expenditures have a positive relationship with green innovation activities.
Hypothesis 5 (H5): External R&D expenditures have a positive relationship with green innovation activities.

2.5. R&D intensity and green innovation

There are various methods for measuring R&D intensity: the ratio of R&D investment to net sales (Rezende et al., 2019), the ratio of internal R&D expenditure to total turnover (López, 2008) and R&D employees as a percentage of total employees (De Marchi, 2012; Sánchez-Sellero et al., 2014a; Huergo and Moreno, 2017). Internal R&D efforts can help firms exchange knowledge with other institutions and improve their absorptive capacity (Díez-Vial and Fernández-Olmos, 2015; Tsai, 2002).

Many studies reveal that internal R&D efforts are also important in promoting green innovation (Triguero and Alvarez, 2017; Horbach, 2008). Moreover, they help firms introduce new products and processes by integrating internal information and ideas with external knowledge (Díez-Vial and Fernández-Olmos, 2015). Kim and Kim (2018) find a strong relation between environmental expenditures and R&D intensity. In contrast, Baumann and Kritikos (2016) find that R&D intensity has a positive effect on innovative companies, but the effect of product innovation is higher than the effect of process innovation. In the same vein, Triguero et al. (2017) find a positive effect of R&D intensity on green innovation and employment growth.

Notwithstanding, many studies find a negative relationship between R&D intensity and green innovation (De Marchi, 2012; Horbach, 2008). This could lead us to deduce that the effect of R&D intensity on environmental innovation depends on different factors, including financial position and relationships with stakeholders (Triguero et al., 2017). However, environmental innovation is also influenced by a combination of R&D intensity, firm capabilities and innovativeness (Veronica et al., 2020). On this basis, we propose the following hypothesis:

Hypothesis 6 (H6): R&D intensity has a positive relationship with green innovation activities.

The theoretical framework is summarized in figure 1.

(Insert figure 1 about here)

3. Model, data and methodology

3.1. Data

We collect data from the Spanish Technological Innovation Panel (PITEC) (Spanish Ministry of Science and Innovation, 2016) and the Community Innovation Survey (CIS). PITEC is the best dataset to observe innovation activities in Spanish firms over time (Díez-Vial and Fernández-Olmos, 2015). This source allows us to build panel data for firm-level innovation studies by offering more than 460 variables and 12,849 firms in all sectors. We use firm-level microdata on firm practices and different innovation dimensions for 2003–2016. Many studies specifically survey green innovation (De Marchi, 2012; Arranz et al., 2019; Jové-Llopis and Segarra-Blasco, 2018). Thus, PITEC also offers the possibility to make direct comparisons of this work to other works based on CIS data beyond measuring innovation in Spanish firms (Martínez-Ros and Kunapatarawong, 2019). The main variables of this study are *Green innovation*, *Cooperation with partners*, *External R&D expenditures*, *Internal R&D expenditures*, *Public funds and R&D intensity*.

Green innovation. We follow the literature to measure the dimensions of green innovation (De Marchi, 2012; Martínez-Ros and Kunapatarawong, 2019; García-Marco et al., 2020). First, *PEGR* indicates activities that lead to "less energy or/and materials per unit produced". Second, *HSEGR* refers to activities oriented toward "improvement of health, safety and the environment". Last, *REGR* represents "compliance with environmental and regulatory requirements". We classify the variables as not applicable, low, medium or high if the values are 0, (0.5, 1), (1.5, 2) and (2.5, 3), respectively.

Cooperation with partners. We measure cooperation with partners using seven dummy variables that measure whether a firm conducts mutual R&D activities with external partners. Thus, these dummy variables show cooperation with an affiliated company in the same group (*COAFF*), suppliers (*COSUP*), customers / clients (*COCL*), competitors (*COCOM*), experts or consulting firms (*COEXP*), universities (*COUNIV*) and public research institutions or technology centers (*COPUB*). These dummy variables equal 1 if the firm has R&D cooperation with external partners and zero otherwise.

Public funds. We consider public funds (*FIN*) as independent variables. The dummy variable *FIN* equals 1 if a firm receives some financial support for innovation activities from local or regional institutions, national governments, or the European Union; it equals zero otherwise.

R&D expenditures and R&D intensity. We measure internal and external R&D expenditures via internal R&D activities or interaction with external institutions. Sánchez-Sellero et al. (2014b) state that businesses with the best resources and capacities show the greatest capacity to absorb knowledge. We use independent variables *(RDIN)* and *(RDEX)* to indicate if a firm has internal or external R&D expenditures, respectively. These variables equal 1 if a firm has internal and/or external R&D expenditures; it equals zero otherwise. R&D intensity (*INTENSITY*) is the ratio of the number of employees working in the R&D department to total staff (De Marchi, 2012; Huergo and Moreno, 2017).

3.2. Control variable

Firm size is one of the main factors in adopting a green innovation strategy (Jové-Llopis and Segarra-Blasco, 2018). It is the natural logarithm of the number of employees (*Ln(SIZE)*), which we use to stabilize variance and get asymptomatically to normality, as is common in management studies (Carroll and Stater, 2009). Many scholars use *SIZE* as a control variable too (De Marchi, 2012; Jové-Llopis and Segarra-Blasco, 2018).

(Insert table 1 about here)

3.3. Model and methodology

This study uses a fixed-effect FE regression with unbalanced panel data. The main difference between the fixed-effect FE model and the random-effect RE model is whether the unobserved individual effect embodies elements that are correlated with the regressors. For RE, unlike FE, the variation across entities is supposed to be random and uncorrelated with the predictor or independent variables in the model (Greene, 2008). We prefer FE estimation because the FE estimator deals with variables that do not change over time; also, it helps control or minimize biases for omitted variables due to unobserved heterogeneity (Dranove, 2012). Therefore, we use the Durbin Wu-Hausman test to choose between both models. FE estimators are always consistent in the panel data when the Hausman test results are significant at the 1 % level; thus, we select the fixed-effect model (Cameron and Trivedi, 2005). We estimate the following three regressions:

$$\mathrm{PEGR_{it}} = \alpha + \beta_1 * \mathrm{COAFF_{it}} + \beta_2 * \mathrm{COSUP_{it}} + \beta_3 * \mathrm{COCL_{it}} + \beta_4 * \mathrm{COCOM_{it}} + \beta_5 * \mathrm{COEXP_{it}} + \beta_6 * \mathrm{COUNIV_{it}} + \beta_7 * \mathrm{COPUB_{it}} + \beta_8 * \mathrm{FIN_{it}} + \beta_9 * \mathrm{RDIN_{it}} + \beta_{10} * \mathrm{RDEX_{it}} + \beta_{11} * \mathrm{INTENSITY_{it}} + \beta_{12} * \ln(\mathrm{SIZE_{it}}) + \tau_t + \mathcal{E}_{it}$$

$$\mathrm{HSEGR_{it}} = \alpha + \beta_1 * \mathrm{COAFF_{it}} + \beta_2 * \mathrm{COSUP_{it}} + \beta_3 * \mathrm{COCL_{it}} + \beta_4 * \mathrm{COCOM_{it}} + \beta_5 * \mathrm{COEXP_{it}} + \beta_6 * \mathrm{COUNIV_{it}} + \beta_7 * \mathrm{COPUB_{it}} + \beta_8 * \mathrm{FIN_{it}} + \beta_9 * \mathrm{RDIN_{it}} + \beta_{10} * \mathrm{RDEX_{it}} + \beta_{11} * \mathrm{INTENSITY_{it}} + \beta_{12} * \ln(\mathrm{SIZE_{it}}) + \tau_t + \mathcal{E}_{it}$$

$$\mathrm{REGR_{it}} = \alpha + \beta_1 * \mathrm{COAFF_{it}} + \beta_2 * \mathrm{COSUP_{it}} + \beta_3 * \mathrm{COCL_{it}} + \beta_4 * \mathrm{COCOM_{it}} + \beta_5 * \mathrm{COEXP_{it}} + \beta_6 * \mathrm{COUNIV_{it}} + \beta_7 * \mathrm{COPUB_{it}} + \beta_8 * \mathrm{FIN_{it}} + \beta_9 * \mathrm{RDIN_{it}} + \beta_{10} * \mathrm{RDEX_{it}} + \beta_{11} * \mathrm{INTENSITY_{it}} + \beta_{12} * \ln(\mathrm{SIZE_{it}}) + \tau_t + \mathcal{E}_{it}$$

Where:
i: firm
t: year
α: constant coefficient
ß: regression coefficient
τ_t: year coefficient
$\mathcal{E}_{it}$: error term

Notably, our models test the influence of R&D practices on green innovation activities in Spanish firm (*i*) over time (*t*), where dependent variables *PEGR*, *HSEGR* and *REGR* are proxies of green innovation and measure the degree of adoption of green objectives in a firm, which encompass material and energy efficiency; improvements in health, safety, and environmental practices; and compliance with environmental regulations, respectively.

The literature recognizes the importance of R&D practices and the combination of internal and external R&D efforts to promote green innovation. In particular, external practices include R&D subsidies, cooperation, information exchange, environmental regulations and market demand (Del Río et al., 2015). In this manner, building relationships with external partners helps firms exchange knowledge, acquire new skills and enhance resource efficiency. These partners have diverse impacts on environmental innovation; however, we outline seven types of partners that scholars explore (De Marchi, 2012): *COAFF*, *COSUP*, *COCL*, *COCOM*, *COEXP*, *COUNIV* and *COPUB*. Furthermore, R&D subsidies have an important influence on reducing uncertainty and sharing the risk of losses in green ventures. In our study, we detect various sources of public funds *FIN* that represent national, regional or European entities.

Internal practices include technological capabilities and firm features such as size and financial position. However, applying strict environmental regulations requires broader workforce knowledge, expertise, and training, as well as adherence to environmental standards and policies (García-Marco et al., 2020). To such an extent, *RDIN* and *INTENSITY* improve firm capabilities by encouraging innovative ideas, adoption of new technology and integrating external knowledge simultaneously (Díez-Vial and Fernández-Olmos, 2015). Accordingly, bigger firms *Ln(SIZE)* are more able to apply various green activities.

4. Estimation and discussion

We use Stata 14.0. Table 1 shows the descriptive statistics (mean, standard deviation, minimum and maximum), and table 2 reveals the correlation matrix and variance inflation factors (VIF) that use a statistical technique to check whether multicollinearity exists between independent variables. However, the results indicate significant relationships between independent variables, and there is not a high correlation between any two variables; none have VIF values more than 10, and the tolerance values are not less than (0.1). Thus, there is no multicollinearity.

(Insert table 2 about here)

Table 3 reports the regression results from three models to investigate how R&D practices affect green innovation activities in Spanish firms with 96,326 observations. In this manner, models 1, 2 and 3 represent green innovation activities via *PEGR*, *HSEGR* and *REGR*, respectively.

(Insert table 3 about here)

Based on the main outcomes, we note that establishing R&D agreements with external partners is the main driver of green innovations because they contribute to developing firms' technological capabilities. These partners involve *COAFF, COSUP, COCL, COCOM, COEXP, COUNIV* and *COPUB*. However, this study also distinguishes between the roles of different external partners to enhance green innovation.

Despite the importance of building outside networks, not all partners make equally important contributions. However, collaboration with suppliers is a primary source of product and process innovation, as well as environmental innovation (Geffen and Rothenberg, 2000); thus, it is preferable to partner on green innovations. In this manner, the results show that cooperation with suppliers

COSUP has a strongly positive and the most significant relationship with green innovation activities in all models. Thus we confirm H1, which is consistent with (De Marchi, 2012).

In contrast, H2 indicates that R&D cooperation with competitors *COCOM* has a favorable effect on green innovation activities beyond the competition area. The coefficient of *COCOM* is not significant and negative, which is in line with previous literature (De Marchi, 2012; Triguero et al., 2017). However, we find a positive relationship among *COCOM* in models 2 and 3, environmental managerial practices and adherence to regulatory requirements. This situation occurs because firms concerned with mutually beneficial exchanges of general knowledge, skills and solutions to common issues with competitors create win-win strategies among rivals (Tether, 2002; Horbach, 2016). Thus, we confirm H2. Accordingly, building relationships with competitors is restricted in common managerial and regulatory affairs beyond the competition area because firms consider them threats and obstacles to expanding their market share.

We show the relevance of public funds *FIN* to green innovation through persistent R&D funding, which helps firms achieve financial stability in order to implement supplementary environmental projects with supposed risk (Aschhoff, 2009). These subsidies also reinforce overall firm performance in the long term (Plank and Doblinger, 2018). These arguments match our research results, which find that *FIN* has a significant positive coefficient on green innovation in all models. Thus, we accept H3. This result is similar to previous studies (Souto and Rodriguez, 2015; Arranz et al., 2019; Jové-Llopis and Segarra-Blasco, 2018; De Marchi, 2012).

R&D expenditures represent the R&D process (Fujii and Managi, 2019) and efforts to improve internal capabilities and absorptive capacity (De Marchi, 2012; Del Río, 2015). Thus, firms that invest more in R&D are better able to acquire skills and exchange knowledge, as well as apply innovative green projects and obtain competitive advantages. The coefficients of *RDIN* and *RDEX* are positive and highly significant in all models; thus, we confirm H4 and H5. In this way, *RDIN* and *RDEX* complement each other, especially in manufacturing and high-tech sectors. These findings are consistent with the literature (Jové-Llopis and Segarra-Blasco, 2018; Fujii and Managi, 2019).

R&D intensity *INTENSITY* also has a significant effect on green innovation. Our results confirm H6, which predicts a positive relationship between *INTENSITY* and green innovation across all models. Internal R&D resources enhance green innovation, increase competitiveness and increase firm growth (Triguero et al., 2017). Notably, *INTENSITY* also reflects internal R&D expenditures because the labor costs of existing R&D employees are internal R&D expenditures. Overall, firms can apply internal and external R&D methods; this relies on various factors such as industry type, technological level and firms' financial position.

Ln(SIZE) has a significant and positive effect on green innovation activities. This suggests that larger firms may do a better job of implementing green innovation. This result is consistent with the literature (De Marchi, 2012; Horbach, 2008; Jové-Llopis and Segarra-Blasco, 2018).

5. Concluding Remarks

The overall performance of green innovation inputs in Spain is lower than the EU average. National and regional policies support green innovation and sustainable development in Spain in order to boost environmental innovation, resource efficiency and clean technologies (European Commission, 2017). We make various contributions to the literature on green innovation and R&D practices.

First, we use PITEC panel data from 2003 to 2016 for 12,849 firms in all sectors in Spain. This database provides observations form many factors over a long time. Most studies of green innovation use cross-sectional data, time series, or panel data for a short period and small sample.

Second, this research measures the influence of internal and external R&D practices green innovation. Furthermore, we differentiate between these practices and explore their influence on green innovation activity separately. In addition, the study provides empirical evidence of how external partners absorb knowledge and optimize R&D practices in order to adopt green innovation strategies. Our paper complements the previous literature (De Marchi, 2012; Triguero et al., 2017; Arranz et al., 2019).

Third, we detect the relevance of subsidies to enhance firm efficiency and the risk reductions related to environmental innovation by exploring the influence of public funds.

Overall, our main purpose is to study how R&D practices inside and outside firms affect green innovation activities over time. We also explore the differences between types of external partners and the effect of subsidies on firms' capabilities. R&D efforts are the main drivers of green innovation and our results align with previous studies. Thus, we detect R&D practices and capabilities that affect firm activities on environmental issues. We develop and extend the literature on the factors controlling firms' activities and agreements with external partners that boost absorptive capacity and green practices in Spanish firms. We use firm-level PITEC panel data for 14 years. Furthermore, we apply a fixed-effect model to control for unobserved heterogeneity over time. We study three target factors of green innovation: efficient use of materials and energy; advancement of health, safety, and environment in firm ventures; and commitment to environmental requirements.

The study findings indicate that cooperation with external partners is positively associated with green innovation regarding compliance with environmental requirements and safety and health applications in Spanish firms. External sources boost the efficient use of materials and energy, excepting the cooperation with competitors. We find a negative relationship with competitors. This is because agreements with competitors concentrate on general knowledge and skills, and finding solutions to common issues is beyond the competitive area among the firms. In addition, we find a positive association between internal and external R&D expenditures on green innovation activities. This could reflect an existing complementary relationship and robust relevance between spending inside and outside firms, which depends on firms' absorptive capacity. Additionally, we find a positive relationship between subsidies and green innovation activities. The reason is that governments and public funds pay more attention to issues related to the environment by supporting firms that reduce the risk of green investments and therefore maintain economic stability and the environment. R&D intensity also has a significant impact on all green activities, despite a few studies detecting a negative relationship. This effect does not happen immediately. As we anticipate, firm size plays an essential role in a firm's potential to refine green innovation activities. Larger firms can obtain more loans and subsidies and provide guarantees.

The main implication for decision-makers is that internal and external R&D efforts are related with green innovation and the two complement each other. R&D expenditures should fit a firm's capabilities and reflect a compromise between revenues and green projects on one hand, and growth and competitive advantages on other hand. Moreover, cooperation with suppliers is a considerable source of green competence in the market, which facilitates the provision of advanced and innovative green technology, as well as knowledge and experience that meets market needs. These significant contributions to the literature open new research avenues. New studies could differentiate between sectors, which are an important factor in environmental issues, as pollution and energy consumption levels vary by industrial and service sectors.

Despite these significant contributions to the literature, some constraints exist. First, this study does not differentiate between sectors considered important factors in environmental issues, where pollution and energy-consumption levels are not similar. Second, the PITEC dataset is designed to measure innovation, but it is not directed to measure green innovation specifically. Thus, we do not distinguish between the influence of R&D practices on green product innovation and green process innovation.

There are also important questions about how green innovation influences competitive advantages and financial performance, as well as the possible differences in applying green practices among affiliates in multinational firms. Further research could find measures to determine green innovation attributes, differentiate between them based on location, and distinguish among different sources of public funds in green projects. Also, new papers could consider green practices in human resource management and supply chains.

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R&D; green innovation; cooperation, environmental innovation

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No potential conflict of interest was reported by the authors.

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