Environmental innovation and R&D cooperation: empirical evidence from Spanish manufacturing firms

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Abstract

This paper explores the relationship between firms' R&D cooperation strategies and their propensity to introduce environmental innovations.

Previous literature has supported that environmental innovations differs from other innovations as far as externalities and drivers of their introduction are concerned, highlighting mainly the importance of regulation to trigger them. Using data from the Community Innovation Survey on Spanish manufacturing firms (PITEC), this paper investigates specificities that affect rather how they are developed, and in particular the higher importance of R&D cooperation with external partners.

The econometric estimations, controlling for selection bias, suggest that environmental innovative firms cooperate on innovation with external partners to a higher extent than other innovative firms. Furthermore, cooperation with suppliers, KIBS and universities is more relevant than for other innovators, whereas cooperation with clients does not seem to be differentially important. Finally, the results bespoke of a substitution effect between cooperation activities and the internal R&D effort.

Keywords: environmental innovation, R&D cooperation, two-part logit model, innovation survey, Spain

1. Introduction

The importance of the environmental agenda for industry has been rising exponentially at the international level in recent years. On the one hand, increasing consumers' awareness on the environmental impact of their consumption choices and their willingness to reduce the ecological footprint (Harrison et al., 2005) creates new market opportunities for companies. On the other hand, increasingly restrictive policies punishing environmentally-harmful behaviors and the action of NGOs, which raises the attention on firms' polluting activities (Porter and van der Linde, 1995; Spar and Mure, 2003), encourage firms to control the effects of their activities on the environment to reduce reputation risks and avoid additional costs.

The way companies integrate environmental concerns into their strategies while consolidating their competitive advantage is through environmental innovations. Despite the interest on environmental innovations is on the rise, research on this field is still limited. A number of studies supported that those

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innovations differs from other innovations as far as externalities and drivers of their introduction are concerned, highlighting mainly the importance of regulation to trigger them (e.g., Porter and van der Linde, 1995; Rennings, 2000; Jaffe et al., 2002, 2005). However, there is still little empirical evidence on specificities of those innovations regarding how they are conceived and realized, notwithstanding the importance for policy-making and the development of firms' strategies. In this paper, it is argued that, given their systemic, credence and complex character, environmental innovations are peculiar in that R&D cooperation with external partners is even more important than for the introduction of other innovations. Evidence that networking activities may be an important driver for environmental innovation (Hemmelskamp, 1999; Mazzanti and Zoboli, 2005; Horbach, 2008) and especially that a strong partnership with suppliers and network partners may be a powerful spur to application of innovative environmental technologies (Andersen, 1999; Geffen and Rothenberg, 2000; Andersen, 2002; Simpson et al., 2007) has been found. However, this literature is lacking in the empirical setting, being mainly qualitative or focused on restricted geographic areas and, with the notable exception of Horbach (2008), does not allow for comparison with non-environmental innovations.

Against this background, this paper investigates the relationship between R&D cooperation and environmental innovation through a statistical analysis based on the Spanish Innovation Survey (PITEC). The contribution of the paper is multifold. First, it provides a comparative analysis of the importance of R&D cooperation and internal technological capabilities for environmental innovation as compared to other types of innovation. If the majority of the quantitative analyses on green innovation so far has focused just on green innovators (see e.g., Mazzanti and Zoboli, 2005; Rennings et al., 2006), the approach used in this paper will allow comprehending if and to what extent they differ from other types of innovation. Second, it investigates R&D cooperation differentiating between types of cooperation partners – considering vertical, horizontal and lateral cooperative agreements – acknowledging the literature on innovation that highlights the different role of these partners in the innovation process (Tether, 2002; Belderbos et al., 2004a,b). Finally, this paper contributes to the literature on environmental innovations from a methodological standpoint. The econometric model used allow testing the hypothesis against possible selection bias due to the necessary exclusion from the analysis of non-innovative firms, improving the scant empirical evidence in the literature (Horbach, 2008).

The remainder of the paper is organized in four sections. The following explores the relevant literature and specifies the hypotheses for the analysis, section 3 describes the data, the variables and the econometric specification used in the empirical analysis and section 4 presents the results. Finally, section 5 contains the conclusions, the limitations of the study and indications for future research.

2. Conceptual background and hypotheses

2.1. Is green innovation different?

Green, sustainable, environmental or eco-innovation may be defined as "new or modified processes, techniques, practices, systems and products to avoid or reduce environmental harms" (Kemp et al., 2001; Beise and Rennings, 2005). This definition includes all the changes in the product portfolio or in the production processes that tackles sustainability targets, like waste management, eco-efficiency, reduction of emissions, recycling, eco-design or any other action implemented by firms to reduce their environmental footprint. It is worth noting that this definition is based on the effect of the innovation activities independent of the initial intent and includes both incremental and radical improvements.

A crucial question environmental innovation scholars deal with is if those innovations, which are increasingly at the center of the policy action, need for a specific theory and policy or not. So far, the literature, especially neoclassical contributions, has focused mainly on two aspects that differentiate them from other innovations, which regard their externalities and drivers – what Rennings (2000) named the "double externality problem" and the "regulatory push/pull effect". As it has been widely discussed in the general innovation literature – the literature on innovation that do not focus specifically on the environmental one – innovation and R&D activities are characterized by positive externalities: the incentive for firms to invest in them lessen as they cannot fully appropriate the value created, because of knowledge spillovers that benefit other firms. In addition, green innovators produce also an environmental positive externality. Since part of the value created is appropriated by society – in the form of reduced environmental damage – rather than by the firms that invested in cleaner technologies, which bear higher costs than polluting competitors, there is a disincentive for firms to invest in products or process that reduce environmental impacts (see Rennings, 2000; Jaffe et al., 2005). The market-failure derived by the interaction of those two externalities induces a second peculiarity of eco-innovations: the greater importance of the policy intervention to drive their introduction (Rennings, 2000). The general innovation literature has highlighted the role of demand-pull and technology-push factors as determinants of innovation. Several contributions focusing on environmental innovations support that, given the low private incentives for firm to invest in them, the regulatory and institutional frameworks are to be considered as additional key determinants of their introduction (e.g., Porter and van der Linde, 1995; Cleff and Rennings, 1999; Kemp, 2000; Jaffe et al., 2002), especially for the development of the more radical changes of technological systems toward the greening of industries (Freeman, 1992; Rennings, 2000; Foxon and Andersen, 2009).

Table 1 summarized those peculiarities of environmental innovations, which by now have received the highest attention in the literature on eco-innovations. If they have been corroborated by a vast empirical literature, less explored are other peculiarities, which affect rather how eco-innovations are developed, in particular with respect to the importance of cooperative arrangements for their realization. General innovation studies have underlined that, to develop new products or processes, firms increasingly

Table 1: Main peculiarities of environmental innovations as compared to other types of innovations, identified by neoclassical contributions in the environmental innovation economics literature

	Environmental innovations	Other innovations
Externalities	Knowledge externalities and environmental externalities	Knowledge externalities
Drivers	Demand-pull, technology push and regulatory push/pull factors	Demand-pull and technology push factors

cooperate with lead users, suppliers, universities and the like rather than relying just on internal resources (Von Hippel, 1988; Chesbrough, 2003; Belderbos et al., 2004b). The systemic, credence and complex character of environmental innovations suggest that, to develop them, cooperation may be even more important than when it comes to introduce other types of innovations.

Studies spanning from the innovation systems and evolutionary economic literatures describe environmental innovations as systemic, requiring a higher cooperative effort and implying higher complementarities with the activities performed by network partners (Andersen, 1999, 2002; Foxon and Andersen, 2009). Eco-innovation, in fact, very often requires changes in the raw materials or components used, the logistical and technical integration with external partners and the re-design of products. Cooperation with suppliers is important to ensure the supply of inputs or components with eco-friendly features – which may not be readily available on the market – to verify that they fulfill the requirements or to modify the internal production process accordingly (Geffen and Rothenberg, 2000; Meyer and Hohmann, 2000; Goldbach, 2003; Seuring and Müller, 2008). Technical and organizational interdependencies with suppliers and business clients are increasing as firms attempt to close their production cycles and enhance recyclability (see Seuring and Müller, 2008). Furthermore, to carry out a product that reduces environmental impacts is a rather complex task and often requires information and skills distant from the traditional knowledge base of the industry. Eco-innovations represent a technological frontier on which firms are still inexperienced and market and technological uncertainties increase as there are not widespread-accepted standards neither in terms of specific technological solutions nor of measures to evaluate the environmental performance of products and processes.

Finally, the environmental feature of a product or process is often a hidden attribute that cannot be disentangled even after the purchase (Andersen, 1999). Darby and Karny (1973) named the goods with these qualities "credence goods", since their value cannot be evaluated in normal use but, if possible, can be assessed just by acquiring additional costly information. Just in very few instances, when purchasing a product, it is possible to understand if it has been done through a less polluting production process or using a less impacting raw material. This information problem affects both consumers' purchases of final products and firm's purchases of raw materials or components. Firms therefore are impelled, on the one hand, to reassure consumers about the environmental features of their eco-friendly products to attain their preference (Rex and Baumann, 2007), on the other hand, to verify the characteristics of the inputs they are buying – which is often reached through closer relations with supply-chain partners.

Voluntary environmental certifications, which are increasingly used as tools to mitigate this information problem (Baksi and Bose, 2007; Rex and Baumann, 2007), reinforce the need for a closer relationship with those partners, since they require firms to be responsible for the environmental performance of all the components of their products.

2.2. Testable hypotheses

The literature on innovation suggest that firms cooperate on innovative activities both to reduce transactions costs and share risks – especially for investments characterized by uncertainties – and to complement their internal resources and skills (e.g., Tether, 2002; Miotti and Sachwald, 2003; Belderbos et al., 2004b). Cooperation with external partners proved to be valuable especially in the case of highly R&D intense sectors and for innovations that are radical or imply knowledge and skills that fall outside the firms' usual domain (e.g., Bayona et al., 2001; Miotti and Sachwald, 2003), which is often the case for eco-innovations. The interdependences arising because of their systemic and complex character and the uncertainties linked with their development motivate firms introducing environmental innovations to leverage on the competences of external partners to a higher extent than for other innovations. Similarly, the need to ensure about the environmental features of all components used spurs firms to interact to a higher degree with their supply chain partners, both to co-develop innovations and to verify their compliance.

The importance of cooperation in seeking environmental innovations has recently been suggested also by empirical analyses, even if the evidence is still scant and sparse. In particular, the analysis by Mazzanti and Zoboli (2005) on district firms shows that networking activities may be a major driver for environmental innovation, even more important than structural characteristics of firms such as size. They interpret this result as evidence that cooperative agreements, what they refer to as "horizontal economies of scale", "might matter even more than internal economies of scale". If their analysis does not allow comparing green innovations with non-green ones, the analysis of Horbach (2008) on German firms overcome this limitation, even though it suffers from methodological weaknesses, since it does not control for selection bias. His results support that R&D cooperation is more important for green innovations than for non-green ones. In sum, I hypothesize:

Hypothesis 1 *R&D cooperation promotes environmental innovation to a greater extent than other innovation.*

Theoretical and empirical contributions within the innovation literature argue that the determinants of R&D cooperation (Tether, 2002; Belderbos et al., 2004a; Piga and Vivarelli, 2004) and its impact on firm's innovative performance (Miotti and Sachwald, 2003; Belderbos et al., 2004b; Iammarino et al., 2009) may differ according to the partner type. Cooperation with customers is found to be important especially to reduce market introduction risks and improve products (e.g., Von Hippel, 1988), with suppliers to enhance efficiency and complement the technological base of the firm (e.g., Clark, 1989; Belderbos et al., 2004b) and with universities and research institutes to open new markets and develop complex innovation (e.g., Tether and Tajar, 2008).

As far as green innovation is concerned, just co-innovation with customers and, more often, with suppliers has received particular attention. Cooperation with suppliers may be even more important than to develop other types of innovation, to reduce overall environmental impacts and ensure about the eco-friendly feature of inputs. Exchanges of information on a continuous basis, capability development and reciprocal learning between customers and suppliers, have proved to be key to reach environmental targets (Andersen, 1999; Meyer and Hohmann, 2000; Theyel, 2006) and suppliers' active co-innovating effort to be often necessary for the achievement of higher environmental performance (e.g., Geffen and Rothenberg, 2000). Several case study analyses suggest that a strong partnership with suppliers may be strategic to introduce new products, especially when a change in the firm's inputs is needed (e.g., Meyer and Hohmann, 2000; Goldbach, 2003) and that they may be a source of information that can be even more important than for other innovations (Hemmelskamp, 1999; Theyel, 2006). Similarly, case study analyses have suggested the importance of innovation-oriented cooperation with governmental organizations, universities and national labs for environmental innovation processes (Norberg-Bohm, 2000; Bossink, 2007). Even if we can expect a high importance of research institutions as partners in innovation activities given the complexity to develop environmental innovations, the few theoretical and empirical contributions addressing the topic do not allow hypothesizing if they are differentially important for green with respect to other types of innovation.

Hypothesis 2 *R&D cooperation with suppliers promotes environmental innovation to a greater extent than other innovation.*

The innovation literature suggests that the internal R&D effort is a key complement to co-innovation, increasing the effectiveness of incoming information and knowledge to the development of innovation. R&D, in fact, not only generates new knowledge and eventually innovations, but also increases the "absorptive capacity" of the firm, that is the ability to identify, assimilate and exploit the knowledge coming from external sources (Cohen and Levinthal, 1990). In this view, the internal capabilities of the firms dynamically adapt to and influence the capabilities of external partners, mainly customers and suppliers (see Von Tunzelmann and Wang, 2007). The impact of absorptive capacity on the innovation performance is higher in contexts characterized by high market uncertainties and technological turbulence, where internal prior knowledge become even more important to select and develop external inputs for the successful development of innovations (Lichtenthaler, 2009). The complexity and systemicness of environmental innovations and the market and technological uncertainties that characterize many environmental technologies suggest that they represent such a context, in which complementarities between internal R&D and cooperation strategies are especially important.

Firm-level analyses support that the internal R&D activity is critical for the development of technical environmental innovation (Rennings et al., 2006; Horbach, 2008). However, empirical evidence on the nature of the relation between R&D and external knowledge-sourcing strategies is scarce and mixed, as in the general innovation literature, where, despite several contributions support the complementarity argument (e.g., Tether, 2002; Miotti and Sachwald, 2003; Cassiman and Veugelers, 2006), also evidence of a substitution effect has been found (Laursen and Salter, 2006). Hemmelskamp (1999), in a study of German manufacturing firms, finds evidence to support that eco-innovators have low R&D intensity, which is compensated by the use of external sources of information. This feature, which is stronger especially for product innovations, is seen as evidence of the dominance of end-of-pipe innovations that, being incremental, may require little R&D effort. Mazzanti and Zoboli's results points, instead, to the existence of a synergetic effect: in their analysis, innovation-oriented co-operation with other firms or research institutes is mediated by environmental R&D. They suggest that cooperative agreements – aimed at building up a social capital for developing and introducing innovations – are complementary to the internal environmental-innovative effort of the firms, but their empirical setting does not allow for comparison with non-green innovation. On the contrary, a number of case study analyses, mainly focused on low-tech industries, supports that the internal resources of the firms are even more important than when it comes to introduce other types of innovation, to ensure that information and knowledge flowing from external partners are successfully transformed into new technologies (see e.g., Andersen, 1999; Baraldi, 2008). This discussion leads me to state the following hypothesis:

Hypothesis 3 *Firm's R&D intensity is more likely to be complementary to its cooperation strategy when it comes to environmental rather than other innovation.*

3. Description of the empirical study

3.1. The data for the analysis and the empirical setting

The data for the analysis are drawn from the Spanish Technological Innovation Panel (PITEC)[1], which is carried out yearly by the Spanish National Statistics Institute (INE) in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The rational for the choice of this data set is multifold. Firstly, this data set is based on the Community Innovation Survey (CIS) framework, enabling direct comparisons with results of previous literature on similar data sets. CIS surveys have proved to be a valid and reliable tool to understand innovation dynamics – being among the most used data sets in innovation studies (e.g, Tether, 2002; Miotti and Sachwald, 2003; Laursen and Salter, 2006) – and have already been employed in studies

[1]The data set, the questionnaire and the description of each variable is available free of charge at the website `http://icono.fecyt.es/contenido.asp?dir=05%29Publi/AA%29panel`.

performing comparative analysis on environmental innovations (Hemmelskamp, 1999; Horbach, 2008). Secondly, being the purpose of the study to understand the peculiarities with respect to non-environmental innovations, this data set seemed appropriate since it allows studying both types of innovation, rather than just environmental ones.

Finally, the peculiarities of the Spanish innovation system enable useful comparisons with other countries, and the increasing relevance of environmental issues for the Spanish economy makes it a proper setting to investigate green innovations dynamics. Spain is a moderate and slow-growing innovator. Its main specializations are traditional industries, with a significant development in more advanced industries in recent years (see also Bayona et al., 2001). According to the Eurostat statistics, in 2007, the average expenditure on R&D was 1.27% of the GDP, versus the 1.85% of the EU average. Spain under-performed with respect to other EU27 countries also in terms of overall innovation performance, scoring 0.31 versus 0.45 in terms of Summary Innovation Index, an aggregate innovation-performance index reported in the EU innovation scoreboard. However, Spanish industries benefit from the very active role of the government and higher education sectors, which in 2007 represented almost half (47%) of the total gross domestic expenditures in R&D, much higher than the 33.9% of the EU27 average for the same year. Moreover, Spain has an increasingly high specialization in renewable energies production (in 2007, Spanish wind energy accounted for a quarter of the entire EU27 production), and among the highest number of environmental certified firms throughout all the industries (first European country for ISO14001 and among the first five for number of EMAS and Ecolabel certifications). These results were also due to the increasing policy pressure, aiming both to reduce polluting behaviors and to increase awareness of the importance of environmental matters. Environmental regulation in Spain is incipient but is fast converging to the EU environmental regulation, which is a rather active actor on the international scene (Holzinger et al., 2008; Camisón, 2010). Several environmental laws were introduced in 2006 and 2007, promoting the prevention of pollution and the diffusion of sustainable development practices.

CIS data contain information on companies' structural characteristics, R&D strategies and innovative activities over a 3-years period. In addition, the PITEC data set includes further information on R&D activities, regarding how they are organized, the characteristics of the personnel and their outsourcing. The PITEC is an unbalanced panel. Administered, in the actual form, since 2003, it comprises four sub-samples, to preserve representativeness. The first is composed of firms with 200 employees or more, which represent the 73% of all such firms listed by the Spanish Central Company Directory, while the second is representative of firms with intramural R&D expenditures and is based on the sample of firms part of the survey on R&D activities carried out yearly by INE in coordination with the European Institute of Innovation and Technology (EIT). Starting 2004, two samples of firms with fewer than 200 but higher than 10 employees were added: one of firms reporting external but no intramural R&D expenditures and one with no innovation expenditure. In 2007, the response rate was 90.6%. The changing nature of the sample and of the questionnaire is a limitation of the PITEC that poses challenges for inter-temporal analyses. I therefore decided to focus just on data for one year, 2007, which refers to the period 2005-2007 and provides information on 11,594 active companies. Acknowledging the differences in innovation activities and cooperation patterns between manufacturing and services firms (e.g., Hipp and Grupp, 2005), I restricted the analysis just to manufacturing activities, being left with 6,047 companies.

3.2. The variables for the analysis

3.2.1. How to measure environmental innovation

Environmental patents or environmental investments have been extensively employed as proxies for green innovations (see e.g., Jaffe and Palmer, 1997; Nameroff et al., 2004), yet they could lead to under- or over-estimate innovation, for example in the case of incremental innovations. Following the approach of Horbach (2008), I use instead self-reported data on the effect of the innovations introduced, using a question of the PITEC asking about the "importance of reduced environmental impacts or improved health and safety". Respondents could choose among four possibilities, reporting if this effect was null, low, medium or high. The dependent variable, ENV_INN, takes the value 1 if, in the period 2005-2007, the company reported high or medium importance of this effect and 0 otherwise. This question is therefore used as a filter variable that allow separating firms that introduced environmental innovations from firms that did not. The use of a dummy as dependent variable will allow comparing the emerging evidence with that in the existing literature that already used CIS data sets to analyze similar topics (Brunnermeier and Cohen, 2003; Horbach, 2008). Unfortunately the questionnaire was not designed to investigate specifically green innovation: this variable could be criticized for not capturing it correctly or being too broad. To mitigate this potential problem, different specifications of the dependent variable will be used, testing the robustness of the model.

3.2.2. Engagement in R&D and cooperation for innovation

To verify the hypothesis of the greater importance of cooperation for environmental innovation (hypothesis 1), I use information on the active cooperation on innovation with external partners. The dummy variable COOPERATION indicates if the firm reported to have cooperated on any of the innovation activities with external firms or institutions. The PITEC survey lists seven possible external partners: (1) suppliers of equipment, materials, components or software, (2) clients or customers, (3) competitors or other enterprises of the same industry, (4) consultants, commercial labs or private R&D labs, (5) universities or other higher education institutions, (6) public research institutes, and (7) technological centers. Dummies indicating if the company cooperates with any of those partners have been created to test hypothesis 2 and disentangle the different role of vertical, horizontal and lateral agreements toward environmental innovation. COOPVENDOR is a binary that equals 1 if the company cooperated with partners of typology (1), COOPCLIENT and COOPCOMPET of typology (2) and (3) respectively and

COOPSCIENT if the company cooperated with any scientific agent, i.e., with the remaining partners listed in the survey. To understand the role of R&D and its relationship with external cooperative strategies (hypothesis 3), I employ different measures. The variable R&D_INTENSITY expresses R&D intensity as the ratio between the number of employees working in the R&D department and the total number of employees. Moreover, I included a dummy indicating if the firms perform R&D activities on a continuous basis (CONT_R&D), and its interaction with the variable COOPERATION (the variable COOP_R&D), to test for the complementarity argument.

Other than investing in R&D activities or interacting with external firms or institutions, firms may realize innovation activities benefiting from the acquisition of external knowledge. The variable EXT_R&D indicates expenses on extramural R&D acquisition as percentage of the total expenses devoted to innovation. Similarly, innovation may be allowed by the acquisition of new technologies and machineries that incorporate the needed knowledge. The dummy EQUIPMENT indicates if the firm acquired advanced machinery, equipment and computer hardware or software to produce new or improved products or processes.

3.2.3. Control variables

In addition, I include a number of control variables regarding structural characteristics of the firms and their market strategies. Given that studies on environmental innovation have found that size affects eco-innovation propensity, emphasizing the difficulties of small and medium enterprises in facing the complexity of environmental innovations and the investments needed to switch to greener technologies (see e.g., Hemmelskamp, 1999), I include in the analysis the variable SIZE, measured as the natural logarithm of the number of employees. To control for the possible reliance on the parent firm's resources and knowledge, I included the dummy SUBSIDIARY, valuing 1 if the interviewed firm is a subsidiary of another company, based in Spain or abroad. Furthermore, I control for possible path dependences in the innovation process, which in Horbach (2008) emerges as a determinant of eco-innovations, using the variable INNOVATION04, indicating whether the firm reported to be an innovator in the previous survey wave, regarding the years 2002-2004.

In addition, acknowledging the importance of environmental policy to foster the greening of industries, I include a variable reflecting the public support to innovation. Policy makers may use regulatory instruments or market-based ones to spur the development and diffusion of environmental technologies. Several studies suggest that the second category, which includes subsidies, direct incentives and fiscal benefits that may or may not be specific for environmental innovations (Jaffe et al., 2005), can be even more effective than the first is spurring environmental technologies (e.g., Rennings, 2000). Unfortunately, PITEC data cannot be used to evaluate the impact of regulation on innovation, but allow capturing the impact of market-based instruments. The dummy PUB_FUNDS, used also in the analyses by Horbach and Mazzanti and Zoboli, is based on a question asking if the firm received fiscal benefits, subsidies or any other form of financial support for innovation from local, national or European institutions. Finally, I control for firm's export propensity through the dummy EXPORT – based on a question asking for the percentage of turnover done in foreign markets in 2005-2007 – and its industry specialization – including 13 industry dummies – capturing the impact of different policy restrictions and consumers' awareness in different sectors (see e.g., Brunnermeier and Cohen, 2003).

In the Appendix, table A.1 lists the definition and the descriptive statistics of the variables used and table A.2 reports the simple correlations.

3.3. Method

Since the dependent variable is a dummy, a binary outcome model is used, controlling for possible selection bias arising from the exclusion from the analysis of non-innovative firms. I therefore apply a Two-Part Logit Model (Cameron and Trivedi, 2005; Vega-Jurado et al., 2009), a method that has proved to be appropriate for estimating actual outcomes and more suitable than a Heckman selection model since the dependent variable is binary and not continuous (Haas and Hansen, 2005).

In the first stage, the probability for a firm to become an innovator (PrINNOVATION) is calculated by regressing exogenous variables available for all observations (innovative and non-innovative firms) on INNOVATION, a dummy indicating if the firm introduced any product or process innovation in the period 2005-2007. Similarly to Vega-Jurado et al. (2009), I used as regressors a variable for firm size (SIZE), a variable signaling whether or not the firm is part of a group (GROUP) and industry dummies. Differently from their analysis, variables indicating strictly exogenous obstacles to innovation are included, regarding the high cost of innovation (HAMP_HIGH_COSTS), if the market was dominated by established firms (HAMP_DOMIN_MKT) and if there was no demand for innovation (HAMP_NO_DEMAND). Finally, a dummy variable indicating if the firm was involved in the biotechnology industry (BIOTECH) has been included. The results of the first-stage logit regression are displayed in table A.3 in the Appendix. In the second stage, the main model, non-innovative firms are dropped from the analysis but the inclusion of PrINNOVATION controls for possible selection bias by including the effects of firms that did not innovate. A logit specification is used for both stages.

Unfortunately, given the low number of waves available and the changing nature of the PITEC sample and questionnaire, it was not possible to perform panel data models, to control for potential endogeneity problems coming from the omission of unobservable firm's specific characteristics.

3.4. Descriptive Statistics

Among the innovators, which represent the 76.3% of the firms in the PITEC data set, almost half (47.4%) introduced products or process innovations that had a high or medium positive impact on the environment, the definition of environmental innovators used in this analysis.

Table 2: Environmental innovators, non-environmental innovators and non-innovators by industry, ordered by the relative importance of environmental innovators on the industry total.

	Tot no. of firms	% of envir. innovator	% of other innovator	% of non innovator
Chemicals	610	57.7%	26.2%	16.1%
Pharmaceuticals	164	48.2%	34.1%	17.7%
Transport	340	39.7%	39.1%	21.2%
Non-metallics mineral products and basic metals	519	37.6%	36.0%	26.4%
Wood	113	37.2%	35.4%	27.4%
Food, drink and Tobacco	758	35.6%	38.5%	25.9%
Machinery	835	35.2%	45.4%	19.4%
Electrical	694	33.3%	48.0%	18.7%
Plastics	372	30.4%	44.1%	25.5%
Fabric. metal Products	619	29.6%	43.8%	26.7%
Paper and Printing	279	29.0%	34.4%	36.6%
Textile and Footwear	403	27.5%	41.4%	31.0%
Other Manufacturing Activities	341	29.9%	43.1%	27.0%
Total	6,047	2,188	2,425	1,434

In table 2, I analyze the distribution of green and non-green innovators by industry. The comparative analysis highlights the existence of industry heterogeneity in environmental performance, which is consistent with the results in the extant literature (see e.g., Brunnermeier and Cohen, 2003; Horbach, 2008). In particular, it seems that firms in low-tech industries, such as textile, footwear and plastics are less likely to introduce environmental innovation. In industries implying more complex technologies, instead, there is more heterogeneity: in the chemicals and pharmaceuticals the majority of firms are introducing green innovations, whereas in the machinery and electrical ones this sub-group represents just a minority. Differences in technological opportunities, consumers' awareness, international competitiveness and in policy restrictions may explain this disparity (Brunnermeier and Cohen, 2003). In particular, the analysis by Lopez-Gamero et al. (2009) on selected Spanish industries suggests that each sector is affected by different state or European laws and subsidies availabilities and that this heterogeneity affect differently the greening of industries. In the chemical industry, for example, being an environmentally intensive industry, regulation is stricter and aids and subsidies are higher.

Table 3 reports the descriptive statistics for the regressors, comparing environmental and non-environmental innovators. The two groups of innovators differ especially in terms of degree of networking toward innovation: 37.6% of environmental innovators cooperated with external partners, versus the 24.4% of non-environmental ones. The higher reliance on cooperation is verified for each relation considered but seems to be even more important when it comes to suppliers (20% versus 10.6% of other innovators) and consultants, technological centers, public R&D labs or research institutes (29.9% versus 17.6%).

On average, environmental innovative firms are bigger than non-environmental innovators and they are more likely to export. The innovative effort of the two categories is similar in terms of personnel devoted to R&D yet differs considerably in terms of continuity of such activity (66.1% versus 45.8%). Furthermore,

Table 3: Descriptive statistics of the regressors for environmental and non-environmental innovators.

	Envir. Innovator		Other Innovator	
	Mean	Std. Dev.	Mean	Std. Dev.
COOPERATION	37.6%	0.48	24.4%	0.43
COOPVENDOR	20.0%	0.40	10.6%	0.31
COOPCLIENT	13.4%	0.34	8.0%	0.27
COOPCOMPET	7.5%	0.26	3.9%	0.19
COOPSCIENT	29.9%	0.46	17.6%	0.38
R&D_INTENSITY	11.0%	0.16	9.6%	0.17
CONT_R&D	66.1%	0.47	45.8%	0.50
EXT_R&D	10.62	20.49	8.81	21.36
EQUIPMENT	26.9%	0.44	21.9%	0.41
SIZE	4.34	1.38	3.95	1.30
SUBSIDIARY	31.2%	0.46	25.7%	0.44
INNOVATION04	72.3%	0.45	63.8%	0.48
PUB_FUNDS	44.5%	0.50	33.6%	0.47
EXPORT	62.0%	0.49	56.2%	0.50
	2,188		2,425	

green innovators are more likely to be serial innovators and to have received public funds for innovative activities.

4. Main Results

Table 4: Second-Stage Logit Regression, explaining environmental innovative propensity across Spanish firms considering cooperation strategies.

	(I)		(II)		(III)	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
COOPERATION	0.313***	(0.073)	0.415***	(0.071)	0.760***	(0.122)
R&D_INTENSITY	0.226	(0.235)			0.239	(0.237)
CONT_R&D	0.560***	(0.074)			0.730***	(0.083)
COOP_R&D					-0.669***	(0.147)
EXT_R&D	0.002	(0.002)	0.001	(0.001)	0.002	(0.002)
EQUIPMENT	0.279***	(0.073)	0.243***	(0.073)	0.291***	(0.074)
SIZE	0.110***	(0.033)	0.109***	(0.030)	0.118***	(0.033)
SUBSIDIARY	-0.091	(0.078)	-0.106	(0.077)	-0.088	(0.078)
INNOVATION04	0.154**	(0.070)	0.211***	(0.069)	0.158**	(0.070)
PUB_FUNDS	0.153**	(0.070)	0.250***	(0.067)	0.161**	(0.070)
EXPORT	-0.118*	(0.069)	-0.057	(0.068)	-0.121*	(0.069)
industry dummies	included		included		included	
PrINNOVATION	1.982***	(0.353)	2.426***	(0.345)	1.956***	(0.354)
Constant	-2.628***	(0.261)	-2.805***	(0.254)	-2.739***	(0.263)
Observations	4613		4613		4613	
Pseudo R^2	0.0732		0.0621		0.0765	
Chi square(df)	418.38(23)***		367.08(21)***		436.11(24)***	

Robust standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

Table 4 reports the results for the second-stage logit regression, investigating the impact of cooperative agreements with external partners on environmental innovation propensity. Column (I) reports the complete model, whereas columns (II) and (III) report models with different specifications of the variable measuring internal R&D effort, to test its complementarities with cooperation.

I find strong support for the hypothesis that cooperation is more important to the introduction of environmental innovations rather than non-environmental ones (hypothesis 1). The coefficient of COOPERATION, in fact, is positive and significant in all models.

Table 5: Second-stage logit regression, explaining environmental innovation through the typologies of partners the firms cooperate with.

	(IV)	
	Coef	S.E.
COOPVENDOR	0.382***	(0.109)
COOPCLIENT	-0.123	(0.127)
COOPCOMPET	0.118	(0.154)
COOPSCIENT	0.244***	(0.091)
R&D_INTENSITY	0.219	(0.239)
CONT_R&D	0.549***	(0.074)
EXT_R&D	0.002	(0.002)
EQUIPMENT	0.272***	(0.074)
SIZE	0.100***	(0.033)
SUBSIDIARY	-0.088	(0.078)
INNOVATION04	0.151**	(0.070)
PUB_FUNDS	0.137*	(0.071)
EXPORT	-0.124*	(0.069)
industry dummies	included	
PrINNOVATION	1.970***	(0.353)
Constant	-2.578***	(0.262)
Observations	4613	
Pseudo R^2	0.0756	
Chi square(df)	432.16(24)***	

Robust standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

To test hypothesis 2 on the differential importance of suppliers on innovative activities, I regress eco-innovations on variables indicating the existence of cooperation agreements with specific partners (see table 5). The results support hypothesis 2: the coefficient of COOPVENDOR is actually significant and positive, pointing to the existence of technological interdependencies between green innovators and their vendors. Instead, cooperation with clients (COOPCLIENT) does not seem to affect green innovation to a different degree than other innovations, as cooperation with competitors (COOPCOMPET). Moreover, the interaction with KIBS, universities and other scientific agents (COOPSCIENT) is significantly and positively correlated with environmental innovations.

The econometric analysis supports that R&D activities trigger environmental innovation but not that they are complementary to cooperation with external partners (hypothesis 3). The R&D intensity variable (R&D_INTENSITY) is never significant, as in Horbach (2008), whereas the coefficient of the proxy for continuous R&D activities (CONT_R&D) is significant and consistently positive in explaining green innovative performance. However, the sign of the interactive variable COOP_R&D is negative, suggesting the existence of a substitution effect between external cooperation activities and internal R&D, which contradicts hypothesis 3. Results suggest also that it is not more likely that green innovative firms rely on market relations to develop innovation: the coefficient of EXT_R&D is, in fact, never significant. On the contrary, having acquired machinery, software or the like (EQUIPMENT) positively affect environmental innovation.

The impact of the control variables is consistent for all the models presented. Firm's size (SIZE) seems to be a structural characteristic that boosts green innovations to a greater extent than other innovations. On the contrary, being a subsidiary (SUBSIDIARY) is not differentially significant in explaining the introduction of green innovations with respect to other innovations. Moreover, serial innovators (INNOVATION04) are significantly more likely to introduce green innovations than other types of innovation. The coefficient of the proxy for public financing (PUB_FUNDS) is significant and positive in explaining green innovative performance in all the models, confirming the pivotal role of the institutional context in fostering eco-innovation introduction. Interestingly, EXPORT is weakly significant and its coefficient is negative, indicating that having a local market may be more favorable to market green innovations, as respect to other innovators. Industry dummies confirm the significant positive impact of the chemical and the negative impact of the machinery and electric industries, as emerged from descriptive statistics' analysis. Finally, the coefficient of PrINNOVATION is highly significant in all the models, justifying the choice of using a selection bias model. Using models that do not consider the exclusion of non-innovative firms from the analysis would, in fact, have lead to biased results.

Table 6: Second-stage logit regression, explaining environmental innovation performance using different specifications of the dependent variable.

	(I) ENV_INN		(V) ENV_INN2		(VI) ENV_INN3	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
COOPERATION	0.313***	(0.073)	0.221***	(0.070)	0.200***	(0.077)
R&D_INTENSITY	0.226	(0.235)	0.173	(0.216)	0.205	(0.245)
CONT_R&D	0.560***	(0.074)	0.513***	(0.071)	0.595***	(0.082)
EXT_R&D	0.002	(0.002)	0.002	(0.001)	0.002	(0.002)
EQUIPMENT	0.279***	(0.073)	0.386***	(0.071)	0.290***	(0.077)
SIZE	0.110***	(0.033)	0.129***	(0.031)	0.165***	(0.035)
SUBSIDIARY	-0.091	(0.078)	-0.021	(0.073)	-0.047	(0.081)
INNOVATION04	0.154**	(0.070)	0.129**	(0.065)	0.053	(0.076)
PUB_FUNDS	0.153**	(0.070)	-0.005	(0.066)	0.002	(0.074)
EXPORT	-0.118*	(0.069)	-0.027	(0.065)	-0.047	(0.074)
industry dummies	included		included		included	
PrINNOVATION	1.982***	(0.353)	0.933***	(0.333)	1.218***	(0.395)
Constant	-2.628***	(0.261)	-2.158***	(0.244)	-3.008***	(0.294)
Observations	4613		5136		4613	
Pseudo R^2	0.0732		0.0401		0.0493	
Chi square(df)	418.38(23)***		257.52(23)***		262.7(23)***	

Robust standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

To test the robustness of the results, I considered also different specifications of the dependent variable, focusing on a sub-group of environmental innovations, eco-efficiency ones, namely innovations that minimize the use of resources or reduce process waste. The dummy ENV_INN2 is based on a question asking if the effect of the innovation introduced over the period 2005-2007 was to reduce "materials and energy per unit output" (see also Hemmelskamp, 1999). ENV_INN2 takes on value 1 if the company reported that this effect was high or medium, 0 if low or null. Since this variable could be blamed to capture a cost reduction strategy rather than an aware strategy to reduce environmental impacts, I use as alternative dependent variable also the dummy ENV_INN3, the interaction between ENV_INN and ENV_INN2. In the case the variable values 1, that is when both ENV_INN and ENV_INN2 equal 1, it is likely that the increase in eco-efficiency is part of a broader and explicit strategy to reduce environmental impacts. Columns (I), (V) and (VI) of table 6 reports the second-stage logit regression using, respectively, ENV_INN, ENV_INN2 and ENV_INN3 as the dependent variable. Coefficients' signs and significance levels of the main regressors are consistent along all the models, even if the magnitude of the coefficients for COOPERATION is lower in the models using eco-efficiency measures to proxy environmental innovations. Eco-efficiency innovations, implying the use of the same technologies in a more efficient manner and being likely incremental, may lessen the need for cooperation with external partners.

5. Discussion and conclusions

The raising attention of policy makers and consumers toward the greening of industries makes it increasingly important to understand the peculiarities of environmental innovations in order to target appropriate policies. If the literature so far has identified differences with respect to other innovations regarding mainly their externalities and the driver of their introduction, this paper provided empirical support to theories asserting the existence of peculiarities that affect rather how they are developed and in particular the higher importance of cooperation with external partners. Where the extant contributions on the topic have studied just green innovators or used a qualitative approach, this paper provides a comparative analysis with non-green innovations based on the analysis of a large data set of Spanish manufacturing firms, which control for possible selection bias due to exclusion from the analysis of non-innovative firms. Furthermore, the paper contributes to the literature by investigating R&D cooperation differentiating between types of partner.

The analysis, based on data from the Technological Innovation Panel (PITEC), suggests that R&D cooperation is more intense for environmental innovators than for other innovators, supporting theories asserting that environmental innovations imply higher interdependencies with external partners, because of their systemic, credence and complex features (see e.g., Andersen, 2002, 1999; Theyel, 2006; Seuring and Müller, 2008). Furthermore, results suggest that some categories of partners the firms co-innovate with are more effective than for other innovators. In particular, suppliers emerge as very important partners, corroborating theories asserting the presence of technological interdependencies on knowledge, skills and resources that arise in the development of environmental innovation. Similarly, scientific agents – including universities, consultants and research centers – appear as cooperation partners that are even more important than for other innovations. The complexity to handle sustainability issues may induce firms to rely to a greater extent than for other innovations on those partners, which may provide knowledge-intensive competencies. Conversely, the variable indicating the presence of cooperative agreements with users was not significant, suggesting that their relevance does not vary between the development of green and non-green innovations. This result should not be surprising: environmental features are often not easily detectable by end users and may require very sophisticated technical knowledge to be tackled.

As far as the internal R&D effort is concerned, the results suggest that environmental innovators do not differ from other innovators in terms of resources devoted to R&D activities but rather for the implementation of those activities on a continuous basis. Moreover, results support the existence of a substitution effect between internal R&D activities and R&D cooperation with external partners. This evidence, which is in line with results emerging both in the general innovation literature (see e.g., Laursen and Salter, 2006; Vega-Jurado et al., 2009) and in the environmental one (Hemmelskamp, 1999), should be further verified considering the specific environmental R&D effort rather than the overall one, as in the analysis of Mazzanti and Zoboli (2005), where a complementary effect emerges.

Finally, the analysis confirms that firm's characteristics and internationalization strategies affect environmental innovation propensity. In particular, results suggest that size positively affects eco-innovation propensity and that firms that already introduced new products or processes in the past are more prone to introduce environmental than other types of innovation. Furthermore, results suggest that the policy action, in the form of public grants, fosters innovations that reduce the impact on the environment to a higher extent than other innovations. Interestingly, serving an international market emerged to be significantly and negatively correlated with green innovation. The absence of uniquely recognized standards defining green features together with the fact that environmental are credence characteristics add to the importance of trust, reputation and direct communication efforts, which may be more easily acquired through proximity to the final market.

The analysis of CIS data is useful to gain knowledge on a large number of observations yet has some limitations, as these data sets are not built to assess specifically green innovation nor to evaluate the nature of the relations with external partners. In particular, the dependent variable used is a proxy that not allows distinguishing between firms that introduced just few environmental innovations from other whose entire innovative effort is devoted toward the reduction of environmental impacts. In-depth studies and observational research should be performed to improve this analysis, by further investigating both environmental innovations – better defining them and considering different typologies of innovations – and the relationships with partners – considering for the size of the network and the intensity of the interactions. This study focused just on technological environmental innovations: a great contribution that future research should attempt to provide is to focus also on other forms of innovations, considering for the institutional and social contexts and to investigate eco-innovations in terms of changes in "technology system” and in “techno-economic paradigms” (Freeman, 1992; Rennings, 2000).

Acknowledgments

An earlier version of this paper was part of my Ph.D. thesis. I am grateful to Roberto Grandinetti, Eleonora Di Maria, Maj Munch Andersen, the participants to the presentation at University of Padova, November 2009, and at the Winter Druid Conference, January 2010, and to two anonymous referees for the useful comments. Sincere thanks also to Erich Battistin, Antonio Canale and Veronica Toffolutti for support on the methodology and to the Spanish Institute of Statistics (INE) and Spain’s Science and Technology Foundation (FECYT), for providing the data used.

Appendix A.

See tables A.1, A.2 and A.3.

Table A.1: Description and descriptive statistics of the variables

Variable name	Variable description	Mean	S.D.
INNOVATION	Introduced a product or process innovation - 1 yes, 0 no (E.1.1 and E.2.1)	0.76	0.43
SIZE	Natural logarithm of employees in 2007 (A.7)	4.05	1.37
GROUP	Belongs to a group - 1 yes, 0 no (A.4)	0.37	0.48
BIOTECH	Biotech firm - 1 yes, 0 no (A.9)	0.03	0.16
HAMP_HIGH_COSTS	Importance of high innovation cost as obstacle for innovation - 1 high, to 4 null (F)	2.20	1.10
HAMP_DOMIN_MKT	Importance of presence of established firms as obstacle for innovation - 1 high, to 4 null (F)	2.55	1.07
HAMP_NO_DEMAND	Importance of absence of demand as obstacle for innovation - 1 high, to 4 null (F)	3.26	0.93
ENV_INN	Introduced an innovation with high or medium environmental, safety or health effects - 1 yes, 0 no (E.6)	0.47	0.50
ENV_INN2	Introduced an innovation with high or medium effect of reducing materials or energy per unit produced - 1 yes, 0 no (E.6)	0.40	0.49
ENV_INN3	Introduced an innovation with high or medium environmental, safety or health effects (ENV_INN) and high or medium effect of reducing materials or energy per unit produced (ENV_INN2) - 1 yes, 0 no (E.6)	0.30	0.46
COOPERATION	Cooperation on innovation with external partners - 1 yes, 0 no (E.5.1)	0.29	0.46
COOPVENDOR	Cooperation with vendors - 1 yes, 0 no (E.5.1)	0.14	0.35
COOPCLIENT	Cooperation with clients - 1 yes, 0 no (E.5.1)	0.10	0.30
COOPCOMPET	Cooperation with competitors - 1 yes, 0 no (E.5.1)	0.05	0.23
COOPSCIENT	Cooperation with consultants, universities, public R&D labs or technological centers - 1 yes, 0 no (E.5.1)	0.23	0.42
R&D_INTENSITY	Percentage of R&D employees on total employment (B.3 and A.7)	0.09	0.16
CONT_R&D	Engagement in in-house R&D activities on a continuous basis - 1 yes, 0 no (B.1)	0.46	0.50
COOP_R&D	Cooperation with external partners (COOPERATION) and in-house R&D activities on continuous basis (CONT_R&D) - 1 yes, 0 no	0.21	0.41
EXT_R&D	Percentage of expenditures for extramural R&D on total innovation expenditures (C)	8.68	20.54
EQUIPMENT	Purchased machinery or equipment - 1 yes, 0 no (D.1.C)	0.19	0.39
SUBSIDIARY	Subsidiary of another firm - 1 yes, 0 no (A.4)	0.28	0.45
EXPORT	Turnover in foreign markets - 1 yes, 0 no (A.6)	0.54	0.50
PUB_FUNDS	Received public financial support - 1 yes, 0 no (D.3)	0.33	0.47
PrINNOVATION	Probability of being an innovator, calculated in the first-stage logit regression	0.75	0.14

Note: in parenthesis, the number of the questions in the PITEC questionnaire on which the variables are constructed.

Table A.2: Simple correlations among the independent variables (n=6,047)

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.COOPERATION										
p-value										
2.EXT_R&D	0.144									
p-value	*0.000*									
3.R&D_INTENSITY	0.140	0.036								
p-value	*0.000*	*0.005*								
4.CONT_R&D	0.242	0.040	0.364							
p-value	*0.000*	*0.002*	*0.000*							
5.SIZE	0.124	0.096	-0.282	0.186						
p-value	*0.000*	*0.000*	*0.000*	*0.000*						
6.EXPORT	0.097	0.076	0.028	0.249	0.295					
p-value	*0.000*	*0.000*	*0.032*	*0.000*	*0.000*					
7.EQUIPMENT	0.033	-0.020	0.033	0.064	0.086	0.040				
p-value	*0.018*	*0.117*	*0.011*	*0.000*	*0.000*	*0.002*				
8.SUBSIDIARY	0.070	0.083	-0.097	0.072	0.455	0.139	0.024			
p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.066*			
9.PUB_FUNDS	0.308	0.168	0.280	0.308	0.100	0.112	0.115	0.012		
p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.347*		
10.INNOVATION04	0.102	0.080	0.054	0.256	0.172	0.200	0.034	0.096	0.122	
p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.008*	*0.000*	*0.000*	
11.PrINNOVATION	0.157	0.112	0.106	0.377	0.373	0.284	0.097	0.191	0.220	0.254
p-value	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*

Table A.3: First-stage logit regression

	Coef.	S.E.
SIZE	0.264***	(0.029)
GROUP	0.079	(0.079)
BIOTECH	0.893***	(0.283)
HAMP_HIGH_COSTS	-0.231***	(0.032)
HAMP_DOMIN_MKT	-0.198***	(0.034)
HAMP_NO_DEMAND	0.476***	(0.033)
industry dummies	included	
Constant	-0.561***	(0.185)
Observations	6046	
Pseudo R^2	0.0859	
Chi square(df)	495.83*** (18)	

Robust standard errors.
*** p<0.01, ** p<0.05, * p<0.1.

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