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COOPERATION TOWARD ENVIRONMENTAL INNOVATION: AN EMPIRICAL INVESTIGATION

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Cooperation toward Environmental Innovation: an Empirical Investigation

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Abstract

This paper explores the relationship between firms' cooperation and their propensity toward environmental innovation.

Previous literature has emphasized the peculiarities of such innovations based on their drivers, their positive spill-overs and the importance of regulation to trigger them. This paper contributes to the literature by focusing on the importance of cooperation and of vertical, horizontal and lateral cooperative agreements on environmental innovation propensity. I test these hypotheses through a large scale dataset, the Community Innovation Survey for Spanish firms (PITEC), through the use of estimation techniques that allow to control for possible selection bias.

The econometric estimations suggest that environmental innovative firms cooperate on innovation to an higher extent than other innovative firms. Furthermore, cooperation with suppliers, KIBS and universities is more relevant than for other innovative firms, whereas cooperation with clients does not seem to be differentially important.

Keywords: environmental innovation, cooperation, R&D, two step logit model, innovation survey.

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,

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increasing consumers' awareness of the environmental impact of their consumption choices and their willingness to contribute to reduce the ecological footprint (Auger, Burke, Devinney, and Louviere, 2003; Harrison, Newholm, and Shaw, 2005) creates new market opportunities for companies. On the other hand, increasingly restrictive policies that punish environmentally harmful behaviors, and the actions of NGOs and other environmentalism groups that raise the attention on firms' polluting behaviors (Spar and Mure, 2003; Porter and van der Linde, 1995), encourages firms to control the effects of their activities on the environment in order 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 and separated from mainstream innovation literature.

In particular, there is still little empirical evidence on how these innovations are conceived and made, notwithstanding the importance for policy and the development of firm strategies. Evidence that networking activities may be an important driver for environmental innovation (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 has been found (Andersen, 1999; Geffen and Rothenberg, 2000; Andersen, 2002; Simpson, Power, and Samson, 2007). However, this literature is lacking in the empirical setting, being mainly qualitative or focused on specific geographic areas and, with the notable exception of Horbach (2008), does not allow for comparison with non-environmental innovations.

This paper contribute to fill in these gaps by leveraging on mainstream innovation literature and testing for the impact of cooperation activities on environmental innovation performance through a large dataset on innovative performance of manufacturing firms, the Spanish Innovation Survey (PITEC). The dataset contains information on 6,047 manufacturing firms, their structural characteristics, R&D strategies and firm cooperation activities toward innovation. The analysis of this data contributes to the existing knowledge in many respects. First, a comparative analysis on environmental and non-environmental innovations is performed, rather than focusing just on environmental innovations, to understand if such innovations require a differential effort in terms of cooperation and coordination. Second, extending Mazzanti and Zoboli and Horbach, this paper investigates vertical, horizontal and lateral cooperative agreements, acknowledging the studies on innovation literature that highlight the different role of these partners in the innovation process. Furthermore, this paper contributes to the literature by employing an econometric model that enables testing of these results against possible selection bias, due to the necessary exclusion from the analysis of non-innovative firms.

The paper is organized as follows: section 2 explores the literature on green innovation and cooperation, and introduces the theoretical background and the previous empirical results that motivate the hypotheses. Section 3 describes the data, the variables and the econometric specification used in the empirical analysis and 4 presents the results of the econometric regressions. Finally, section 5 contains the conclusions, the limitations of the study and indications for future research.

2 Conceptual Background

2.1 A literature review of cooperative arrangements for innovation

Studies on the influence of cooperation on innovative activities of firms have mushroomed in recent years, proving through empirical analyses that conventional explanatory variables of innovation performance need to be complemented by investigating collaboration. The early Schumpeterian model of stand-alone developed innovations has been surpassed by the recognition that firms rarely innovate on their own and rely on each other to exchange knowledge, pool resources and share risks (e.g., Håkansson, 1987; Shan, Walker, and Kogut, 1994; Powell, Koput, and Smith-Doerr, 1996). The increasing instability of demand, reduction of product life cycles, disintegration and globalization of production have contributed to take this discussion to the fore in innovation studies. The knowledge base of the companies may quickly become obsolete or insufficient to be competitive and cooperation with other actors of a network become a pivotal competitive factor. Such external partners represent both important sources of information and key resources in the development of innovations (Powell, Koput, and Smith-Doerr, 1996; Von Hippel, 1988; Miotti and Sachwald, 2003; Chesbrough, 2003; Laursen and Salter, 2006).

The management literature discusses the determinants and the modes of cooperation starting from different points of view. The Transaction Cost Approach conceives cooperation toward innovative activities as a form of organization that enables resource access and a better control of the technological transfer while minimizing the risk of opportunistic behaviors, thanks to a mutually dependent relationship (e.g., Pisano, 1990; Williamson, 1991). The traditional argument that interpreted innovation strategies through the *make or buy* dichotomy, namely investing in internal R&D departments or buying knowledge outside the firm, has been surpassed by the recognition that market and hierarchy are actually the end points of a continuum, in which network governance structures are increasingly important (e.g., Håkansson, 1987; Gulati, 1998). The resource-based view literature, instead, interprets partnership and networking for innovation in terms of possibilities to access new skills and pool resources (Penrose, 1959; Wernerfelt, 1984; Powell, Koput, and Smith-Doerr, 1996). Through collaboration with external partners the firms may actually exploit complementary know-how that can be combined with the internal knowledge base to enter new markets or develop new technologies. This strategy is even more valuable in the case of emergent or highly competitive industries or for innovations that are radical or imply knowledge and skills which fall outside the firms' usual domain (Eisenhardt and Schoonhoven, 1996).

However, to cooperate with external partners is not necessarily a winning strategy *per se*. The ability to interact the information and knowledge flowing from this partners with the internal capability base and effort to develop innovation is a key capability. Studies on what has been coined "absorptive capacity" have found support for the hypothesis that the internal R&D efforts increase the effectiveness of incoming information and knowledge (Cohen and Levinthal, 1990). However, the relation between the two is complex. On the one hand, cooperation may be an important substitute for lack of internal resources and effort, on the other hand, the existence of strong absorptive capabilities may enhance firm's returns from the interaction with external partners. Empirical analysis have not solved the puzzle yet: evidence on both the substitution (Laursen and Salter, 2006; Vega-Jurado, Gutierrez-Gracia, and Fernandez-de-Lucio, 2009) and the complementary (Tether, 2002; Miotti and Sachwald, 2003; Cassiman and Veugelers, 2006) arguments have been found.

2.1.1 Cooperation for innovation within the supply chain and beyond

Other than for the characteristics of the innovation or of the industry involved, determinants and impacts of cooperation may vary according to the typology of partner (Belderbos, Carree, Diederen, Lokshin, and Veugelers, 2004; Vega-Jurado, Gutierrez-Gracia, and Fernandez-de-Lucio, 2009).

The research of Von Hippel and others (see e.g., von Hippel, 1976; Von Hippel, 1986, 1988; Thomke and Hippel, 2002; Chesbrough, 2003; Franke and Shah, 2003) has highlighted the key role of consumers in defining innovation, supporting internal R&D effort, identifying markets' needs. Consumers and communities of consumption may contribute to reduce the risk implied by new product's market introduction and improve technical features of the product, especially in the case of high complexity or novelty. The paper by Sanchez-Gonzalez, Gonzalez-Alvarez, and Nieto (2009) identifies two main variables that provide boost for the cooperation with customers: the existence of information that are costly to obtain and use, and the presence of different market niches.

Interest in the role of suppliers as co-innovators arose in the 1980s thanks to the evidence on Japanese automotive and electronic industries, whose success was partly attributed to the suppliers' involvement in their innovation activities. Collaboration with suppliers proved to enhance efficiency, reduce risks or be a necessary complement to the technological base of the firms in the development of innovations, especially under conditions of technological uncertainty (Imai, Nonaka, and Takeuchi, 1985; Clark, 1989; Ragatz, Handfield, and Petersen, 2002). A close involvement of suppliers in the innovation effort, may be an important complement to firm's internal effort to develop both new (or improved) products and processes.

A broad stream of literature has focused the attention also on the role of cooperative agreements with scientific agents on innovation performance and on specific advantages that induce firms to engage with them. In particular, the university-industry link has been attracteing the attention of scholars and governments in recent years. Empirical analyses have found support for the hypotheses that both firm's characteristics, such as size and the industry context, and firm's innovation strategies, regarding the R&D effort, the degree of openness to a variety of information sources and the innovation's content, motivate and influence the extent of interaction with universities (Laursen and Salter, 2004; Segarra-Blasco and Arauzo-Carod, 2008; Sanchez-Gonzalez, Gonzalez-Alvarez, and Nieto, 2009). The recent work of Tether and Tajar (2008) provides new, quantitative, insights also on cooperation agreements with other specialist knowledge providers, including consultancies, private research organizations and public research laboratories. Such knowledge intensive business service firms (KIBS), may play a crucial role in the definition, development or commercialization of technological or managerial innovations and complement other external source of knowledge. Universities, consultants, private labs or public research centers are used by firms as source of knowledge to a different degree, although factors influencing those linkages are similar. The influential study of Cohen, Nelson, and Walsh

(2002) on public specialist knowledge providers reveals that they are used not only to help generate new ideas, but also in completing existing R&D projects. Firms rely on universities and KIBS especially in the field of scientific and technological knowledge, in science-based industries and in the generation of product, rather than process, innovations (Zucker, Darby, and Brewer, 1998; Reichstein and Salter, 2006; Vega-Jurado, Gutierrez-Gracia, and Fernandez-de-Lucio, 2009).

2.2 Is green 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, Arundel, and Smith, 2001; Beise and Rennings, 2005). This definition is purposefully very broad, including all changes in the product portfolio or in the production processes that regard 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 innovation activities independent of the initial intent and includes both incremental and radical improvements.

These innovations, which are increasingly at the center of policy action, represent a distinct sub-group of innovations in many respects. A first peculiarity, besides their positive impact upon the environment, is what Rennings (2000) defined as the "double externality problem". In addition to the spillovers of basic R&D effort studied by innovation economists, environmental innovations generate spillovers also in the diffusion phase, by internalizing the external costs of the impacts on the environment. This double externality causes a reduction in firms' private incentives to invest in such innovations. Policy intervention is then advocated as a potential solution to this market-failure problem. Determinants of eco-innovation turn out to be different: regulation and policy intervention have to be included in the analysis other than the demand-pull and technology-push factors usually considered in mainstream innovation literature (Porter and van der Linde, 1995; Cleff and Rennings, 1999; Rennings, 2000; Kemp, 2000; Jaffe, Newell, and Stavins, 2002).

Other characteristics of green innovations make them peculiar, in particular with respect to the importance of cooperative arrangements. An increasingly influential stream of literature (Andersen, 1999, 2002; Foxon and Andersen, 2009), describes environmental innovations as *systemic*, requiring a higher cooperative effort and implying higher complementarities with the activities performed by network partners. Cooperation with external partners becomes even more important in managing environmental innovations, because of the characteristics of the product and process enhancements. Environmental innovation very often requires changes in the raw materials or components used, the logistical and technical integration with external partners and the re-design of the product. Inputs with environmentally-friendly features are not always readily available on the market, resulting in the need for the firm to engage in cooperation activities with new or established suppliers to realize product innovations (Geffen and Rothenberg, 2000; Meyer and Hohmann, 2000; Goldbach, 2003). To implement changes on the input side often requires a close collaboration with materials and equipment vendors, both to ensure that the new component or input fulfills the required features and to adapt the internal processes accordingly (Seuring, 2004; Seuring and Müller, 2008). Technical and organizational interdependencies among firms are increasing as they attempt to close their production cycles and apply a "life cycle perspective". To use recycled products or to enable the recyclability of their own products, firms may need to engage in closer coordination mechanisms with industrial partners, i.e suppliers and business clients (Andersen, 1999).

Furthermore, the environmental feature of a product or process is often a hidden attribute that cannot be disentangled even after the purchase, creating an information problem. 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 by the mean of a less polluting production process or by using a less impacting raw material. This feature creates information asymmetries at each stage of the supply chain in which an actor is looking to buy a product or a component with a lower environmental impact. To grant the preference to eco-friendly products, customers have to be reassured about its environmental features. Similarly, firms are impelled to understand and control the features of the component and inputs they are buying. These information asymmetries boost firms to have an higher degree of control over their suppliers' activities, which is often reached through closer relations with supply-chain partners. Voluntary environmental certifications are increasingly used as tool to mitigate this information problem (Baksi and Bose, 2007). In turn, these instruments reinforce the need for a closer relationship with value chain partners. Many of the eco-labels, actually, requires firms to be responsible for the environmental performance of all the components of their products, reinforcing interdependencies among partners of the value chain.

Finally, to carry out a product that reduces the impact on the environment is a rather complex task and often requires information and skills distant from the traditional knowledge base of the industry. Exchanges of information on a continuous basis, capability developments and reciprocal learning between customers and suppliers, have proved to be key to reach environmental targets (Andersen, 1999; Aggeri, 1999; Meyer and Hohmann, 2000; Theyel, 2006; Foxon and Andersen, 2009).

2.3 Recent empirical evidence on cooperation and environmental innovation

Evidence corroborating the importance of cooperation in seeking environmental innovations has been found, yet the literature is scant.

Mazzanti and Zoboli (2005) provide useful insights on the relevance of cooperation to achieve environmental innovations by focusing on districts, through the analysis of survey data on 199 manufacturing firms located in the Reggio Emilia province, in Italy. Their results show that networking activities may be a major driver for environmental innovation and, interestingly enough, 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". However, their dataset, being tailored to analyze green innovations, does not allow to understand if the networking attitude of firms is dissimilar than that employed for non-green innovations. The analysis of Horbach (2008) of German manufacturing firms, aimed at understanding the determinants of green innovations, overcomes this problem and provides support to the greater importance of cooperation for green-innovators rather than for non-green ones, even though his results may be challenged since the econometric technique used does not control for possible selection bias coming from the exclusion of non-innovative companies from the analysis. Furthermore, similar to the study of Mazzanti and Zoboli, his analysis does not inquire the relevance of different typology of partners. Nevertheless, as pointed to in many studies in the innovation literature, suppliers, clients and KIBS, may have very different roles as innovative partners.

The role of suppliers in environmental innovation development has been particularly investigated, especially in the Green Supply Chain Management (GSCM) literature. Geffen and Rothenberg (2000), through a case studies analysis on the automotive industry, found that a strong partnership with suppliers is a powerful spur to the application of innovative environmental technologies. Consumers and suppliers may have a key role in the environmental innovating activities of firms, as a source of information that can be even more important than for other innovations (Hemmelskamp, 1999; Theyel, 2006). Other papers have discussed, mainly through case studies analysis and for specific industries, the importance of networking to develop innovations thanks to knowledge transfers and reciprocal learning possibilities (Taylor, Rubin, and Hounshell, 2005) and the importance of cooperation between industry and governmental organizations (Bossink, 2007) or universities and national labs (Norberg-Bohm, 2000) as incentive for environmental innovation.

Analogously to mainstream innovation scholars, *environmental* innovation scholars have investigated the relationship between cooperation with external partners and internal effort toward innovation. The econometric analysis of Rennings, Ziegler, Ankele, and Hoffmann (2006) based on survey data on EMAS-validated German firms points to the importance of internal R&D activities as determinants of environmental innovations, and that of Horbach (2008) provides support to the hypothesis that they are even more critical than for non-environmental innovations. However, evidence on the nature of the relation between R&D and external knowledge sourcing strategies is scarce and mixed. Hemmelskamp (1999), in a study of German firms, finds evidence to support the hypothesis that environmentally innovative companies 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 suggest instead the existence of a synergetic effect between environmental R&D investments and networking activities: in their analysis, the impact of networking activities on environmental innovation is mediated by environmental R&D. The authors present the results as evidence of the "positive relationship between R&D and social capital in an impure public good framework".

In sum, the specificities of environmental innovations imply higher interdependencies with external actors therefore, as previous evidence indicates, cooperation with such partners may be even more important than for other innovations. In the following sections I try to overcome important limitations of the above mentioned literature, by empirically testing the greater importance of collaboration on a large dataset. Secondly, I will analyze the network, to understand which partner may be more important for the development of green innovation. Acknowledging industry and innovation specificities, I expect suppliers and commercial customers to have a paramount role in green innovation dynamics, both as sources of information to conceive and realize the innovations and as partner with whom to collaborate, in order to obtain certifications and eco-labels that enable a successful leverage in final markets. Furthermore, the relationship between networking activities and the internal innovative effort will be analyzed, to contribute to the debate on their synergetic or substituting effect.

3 Description of the empirical study

3.1 Data

To test these hypotheses I use data from the Spanish Innovation Survey, the Technological Innovation Panel (PITEC), which is carried out yearly by the Spanish National Statistics Institute.

The rational for the choice of this dataset is multifold.

Firstly, the purpose of the study being that of understanding the peculiarities with respect to non-environmental innovations, a dataset including information on both type of innovations, rather than just on environmental ones, has been chosen.

Secondly, this dataset is based on the Community Innovation Survey (CIS) framework, enabling direct comparisons with results of previous literature on similar datasets. CIS surveys, administered by national statistical offices throughout the European Union and other countries, have proved to be a valid and reliable tool to understand innovation dynamics. They are among the most used in innovation studies (see e.g., Tether, 2002; Miotti and Sachwald, 2003; Laursen and Salter, 2006; Reichstein and Salter, 2006) and have been employed in the pioneering studies performing comparative analysis on environmental innovations (Horbach, 2008) (see also Andersen (2007) and Kemp and Horbach (2007) for a deeper understanding on possible measure to detect green innovation).

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 innovators' country, underperforming with respect to other EU27 countries in terms of R&D investments (according to the Eurostat statistics, the average expenditure as % of the GDP was 1.27% in 2007, versus the 1.85% of the EU average) and in terms of overall innovation performance (0.31 vs. 0.45) according to the Summary Innovation 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. Furthermore, 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 through all the industries (first european country for ISO14001 and among the first five for number of EMAS and Ecolabel certifications).

The analysis of this paper is based on PITEC data for the year 2007, which provides information on 11,594 companies' structural characteristics, R&D strategies and innovative activities over the period 2005-2007. Acknowledging the differences in innovation activities and cooperation patterns between manufacturing and services firms (see, among others, Abramovsky, Griffith, Macartney, and Miller, 2008), 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; Brunnermeier and Cohen, 2003; Nameroff, Garant, and Albert, 2004), yet shortcomings similar to those analyzed for general innovations warn against the use of those proxies, which could lead to under- or over-estimate innovation, for example in the case of incremental innovations. Following the approach of Horbach (2008), I instead use data reported in the PITEC survey, regarding the answer to the question on the "importance of reduced environmental impacts or improved health and safety" as an effect of the product or process innovation introduced. The dependent variable used in the econometric model, ENV_INN, is then a dummy variable valuing 1 if, in the period 2005-2007, the company reported high or medium importance of this effect on a four-point scale, 0 otherwise. Unfortunately the questionnaire was not designed to investigate specifically green innovations: even if allowing important comparisons with similar works, the choice of this dependent variable could be criticized for being too broad. Different specifications of the dependent variable, including eco-efficiency measures, will be performed to test 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, I use the information regarding the existence of formalized cooperation agreements on innovation with any external partner. 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 each of those partners have been created to disentangle the different role of vertical, horizontal and lateral agreements toward environmental innovation. COOPVENDOR is a binary value equal 1 if the company cooperate with partner of typology (1), COOPCLIENT and COOPCOMPET of typology (2) and (3) respectively, COOPKIBS if the companies cooperate with any scientific agent, so with the remaining partners listed in the survey. To understand the role of internal effort toward innovation and its relationship with external cooperative strategies, I imply different measures. The variable R&D_INTENSITY expresses Research and Development intensity as the ratio between the employees working in the R&D department and the total number of employees. Moreover a dummy indicating the continuity of R&D activities performed by firms were included (CONT_R&D) so as its interaction variable COOP_R&D with the variable COOPERATION 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 benefitting from the acquisition of external knowledge. The PITEC database captures this dimension of innovation asking firms about extramural R&D acquisition. The variable EXT_R&D indicates expenses on external R&D activities as percentage of the total expenses devoted to innovation activities. In some cases innovation is allowed by the acquisition of new technologies and machineries that incorporate the needed knowledge. The dummy variable EQUIPMENT allows to control for this dimension of firms' innovative activities, indicating if they acquired advanced machinery, equipment and computer hardware or software to produce new or improved products or processes.

3.2.3 Structural characteristics of the firm and other control variables

Most empirical studies on innovation consider size as an important explanatory variable of firms' innovative performance: the bigger the firm the more it is likely to enjoy market power, economies of scale or having more resources to dedicate to the development of innovations. Studies on environmental innovation have stressed as well the role of size, emphasizing the difficulties of SMEs in facing the complexity of environmental innovations and the investments needed to switch to greener technologies (Hemmelskamp, 1999). Benchmarking empirical studies on innovation (see e.g., Reichstein and Salter, 2006), I measure size as the logarithm of the number of employees (SIZE).

The variable SUBSIDIARY is a binary variable assuming value 1 if the firm is a subsidiary and 0 otherwise, which controls for the possible reliance on the main firm's resources, skills and knowledge so as for the differential attitude toward environmental issues' experiences by firms affiliated with multinationals.

The dummy variable EXPORT is used to control for the impact of the export activities on environmental innovation propensity. The higher competitive pressures, policy restrictions or the different consumers' awareness that may characterize different countries' markets may actually spur green innovation. Similar heterogeneities may explain also differences among industries (see for example Brunnermeier and Cohen, 2003; Spaargaren, 2003). Therefore, 13 industry dummies are included in the analysis, capturing also specificities regarding market structure, sources and direction of technical change.

Acknowledging the importance of public intervention to fostering the greening of industries yet not having the dataset specific data on regulatory requirements compliance, I control for the influence of policies using a proxy for incentives toward innovation. The binary variable PUB_FUNDS indicates whether or not the firm benefitted from any public funds for innovative activities. Exploiting the time dimension of the PITEC, I investigate the dynamic character of the innovation process through the variable INNOVATION04, which indicates if the firm has reported to be an innovator in the previous period (2002-2004).

3.3 Descriptive Statistics

Among the innovators that represent the 76.3% of the firms in the dataset, almost half (47.4%) were environmental innovators.

Table 1: Environmental innovators, non-environmental innovators and non-innovators by industry, ordered by the relative importance of environmental innovators on the total.

	Tot no. of firms	% of envir. innov.	% of other innov.	% of non innov.
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-metalics 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 1, I analyze the distribution of green and non-green innovators by industry. The comparative analysis between environmental and other innovators highlights the existence of industry heterogeneity in environmental performance. Those differences in the environmental innovative attitude of firms may reflect the diverse advancements in terms of technologies development for greener alternatives but also differences in policy restrictions and consumers' awareness. 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 chemical and pharmaceutical industries the majority of firms are introducing green innovations, whereas in the machinery and electrical ones this sub-group represents just a minority.

Table 2 reports the descriptive results of the main variables comparing environmental and non-environmental innovators. On average, environmental innovative firms are bigger than non-environmental innovators, even though the variability within the first group is much bigger than within the second, 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 the organization of such activities: many more firms claimed to perform

Table 2: Descriptive statistics of the regressors for environmental and non-environmental innovators.

	Envir. Innovative		Other Innovative	
	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
coopkibs	29.9%	0.46	17.6%	0.38
ext_r&d	10.62	20.49	8.81	21.36
r&d_intensity	11.0%	0.16	9.6%	0.17
cont_r&d	66.1%	0.47	45.8%	0.50
equipment	26.9%	0.44	21.9%	0.41
size	4.34	1.38	3.95	1.30
export	63.0%	0.48	57.4%	0.49
subsidiary	31.2%	0.46	25.7%	0.44
pub_funds	44.5%	0.50	33.6%	0.47
innovation04	72.3%	0.45	63.8%	0.48
	2188		2425	

R&D activities on a continuous rather than occasional basis. Furthermore, green innovators seems to have been more able to attract public funds for innovative activities and are more likely to be serial innovators.

Overall, it seems that the two groups of innovators differ especially in terms of degree of networking toward innovation: 37.6% of environmental innovators had at least one cooperative agreement toward innovation with external firms, versus the 24.4% of non-environmental ones. The higher reliance on cooperation is verified for each relation considered, vertical, horizontal and lateral, but seems to be even more important when it comes to vendors (20% vs 10.6% of other innovators) and consultants, technological centers, public R&D labs and of government or public research institutes (29.9% versus 17.6%).

3.4 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), a method that has proved to be appropriate for estimating actual outcomes and more suitable than an 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 on INNOVATION exogenous variables available for all observations (innovative and non-innovative firms). Similarly to Vega-Jurado at al. (2009), I used a variable for firm size (SIZE), a dummy signaling if the firm is part of a group (GROUP) and INDUSTRY DUMMIES to capture technological opportunities and different demand structure. 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 invilved in the Biotechnology industry (BIOTECH) has been included. The results of the first stage logit regression are displayed in Table 6 in the Appendix.

In the second stage, non-innovative firms are dropped from the analysis but the inclusion of PrINNOVATION controls for selection bias by including the effects of firms that did not innovate. A logit specification is used for both stages.

4 Main Results

Table 3 reports the results for the second stage logit regression, investigating the impact of the presence of cooperative agreements with external partners on environmental innovation propensity. Column (I) reports the complete model, whereas columns (II) and (III) report results to test the hypothesis of complementarities with internal R&D effort.

I find strong support for the hypothesis that cooperation promotes the introduction of environmental product or process innovations to a greater extent than non-environmental innovations. The coefficients of COOPERATION are in fact positive and significant in all models. The results are consistent also when excluding from the analysis the internal effort toward innovation, as in model (II).

The econometric analysis provide support to the hypothesis that internal R&D activities trigger environmental innovation. The R&D intensity variable (R&D_INTENSITY) is never significant, whereas the coefficient of the proxy for continuous R&D activities (CONT_R&D) is significant and consistently positive in explaining green innovative performance. The sign of the interactive variable COOP_R&D is negative, suggesting the existence

Table 3: 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)
ext_r&d	0.002	(0.002)	0.001	(0.001)	0.002	(0.002)
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)
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)
export	-0.118*	(0.069)	-0.057	(0.068)	-0.121*	(0.069)
subsidiary	-0.091	(0.078)	-0.106	(0.077)	-0.088	(0.078)
pub_funds	0.153**	(0.070)	0.250***	(0.067)	0.161**	(0.070)
innovation04	0.154**	(0.070)	0.211***	(0.069)	0.158**	(0.070)
prinnovation	1.982***	(0.353)	2.426***	(0.345)	1.956***	(0.354)
industry dummies	included		included		included	
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.

of a substitution effect between external cooperation activities and internal R&D. As expected, 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.

To disentangle the importance of the different typologies of partners involved in cooperation activities, I regress environmental innovations on variables indicating the presence of *vertical, horizontal* and *lateral* collaborations. Table 4 reports the results when including, as regressors, dummies indicating the cooperation with specific partners. The results support the hypothesis that cooperating with suppliers drives green innovations to a greater extent than other innovations. The coefficient of COOPVENDOR is actually significant and positive, pointing to the existence of technological interdependences between green innovators and their vendors. Instead, cooperation with clients does not seem to affect green innovation to a different degree than other innovations, as cooperation with competitors (COOPCOMPET). The interaction with KIBS, universities and other scientific agents (COOPKIBS) is

Table 4: 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)
coopkibs	0.244***	(0.091)
ext_r&d	0.002	(0.002)
r&d_intensity	0.219	(0.239)
cont_r&d	0.549***	(0.074)
equipment	0.272***	(0.074)
size	0.100***	(0.033)
export	-0.124*	(0.069)
subsidiary	-0.088	(0.078)
pub_funds	0.137*	(0.071)
innovation04	0.151**	(0.070)
prinnovation	1.970***	(0.353)
industry dummies	included	
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.

significantly and positively correlated with environmental innovations.

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. Matching this result with the descriptive statistics analysis confirms that green innovators are more likely to be big firms, yet a much higher dispersion is present in their distribution, pointing to the existence of an heterogeneous group of firms that knitted environmental issues to their competitive model. Being a subsidiary (SUBSIDIARY) is not differentially significant in explaining green innovations with respect to other innovations, whereas public financing (PUB_FUNDS) is weakly significant and consistently positive in explaining green innovative performance in all the models. 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. Serial innovators (INNOVATION04) are significantly more likely to introduce green innovations, implying that firms that already introduced new products or processes in the past are more prone to explore environmental than other types of innovation. Industry dummies control for the different incentives and technological trajectories characterizing each sector, and the regression confirms the significant positive impact of the chemical sector and the negative impact of the machinery and electric industry. Finally, the coefficient of PrINNOVATION is highly significant in all the models, therefore 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 have, in fact, lead to biased results.

Table 5: Second Stage Logit Regression, explaining environmental innovation performance using different specifications of the dependent variable.

	(I)		(V)		(VI)	
	ENV_INN		ENV_INN2		ENV_INN3	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
cooperation	0.313***	(0.073)	0.221***	(0.070)	0.200***	(0.077)
ext_r&d	0.002	(0.002)	0.002	(0.001)	0.002	(0.002)
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)
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)
export	-0.118*	(0.069)	-0.027	(0.065)	-0.047	(0.074)
subsidiary	-0.091	(0.078)	-0.021	(0.073)	-0.047	(0.081)
pub_funds	0.153**	(0.070)	-0.005	(0.066)	0.002	(0.074)
innovation04	0.154**	(0.070)	0.129**	(0.065)	0.053	(0.076)
prinnovation	1.982***	(0.353)	0.933***	(0.333)	1.218***	(0.395)
industry dummies	included		included		included	
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, by focusing on a sub-group of environmental innovations. The literature suggests that a way in which firms obtain the joint realization of economic and environmental performance is through eco-efficiency, introducing innovations that reduce the burden on the environment but also the firm's costs. Theoretical and empirical studies have illustrated the possibilities for firms to increase profits by introducing product designs that minimize the use of resources or by reducing process waste. To capture this dimension of environmental innovation, I use a question of the PITEC survey asking, on a four-point scale, if the effect of the innovation was to reduce materials or energy used per unit produced. The variable ENV_INN2 is a dummy variable assuming value 1 if the firm declared that this effect was medium or high. In addition, I test the model on the importance of cooperation also on a variable (ENV_INN3) that allows measure of the combined effect of eco-efficiency and reduced impact on the environment. This variable, an interaction between ENV_INN and ENV_INN2, may better capture the intentionality of the firm to reduce the impact on the environment by the introduction of innovations. Columns (I), (V) and (VI) of table 5 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 COOPERATION's coefficient for the models including eco-efficiency measures (columns (V) and (VI) of table 5) are lower. The sub-group of energy- and material-efficient environmental 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 increasing attention of policy makers and consumers toward the greening of industries makes it important to understand the peculiarities of environmental innovations to target appropriate policies.

This paper contributes to the existing literature asserting that environmental innovation is a distinct sub group of innovation because of its drivers, its positive spill-overs and the importance of regulation (Porter and van der Linde, 1995; Rennings, 2000; Brunnermeier and Cohen, 2003), by inquiring on the antecedents of its successfull implementation, and more specifically, on the impact of cooperation with external partners on environmental innovation propensity.

The econometric analysis, based on a dataset of Spanish manufacturing firms, confirms the hypothesis that cooperation boosts environmental innovation to an higher degree than for other innovations, supporting theories asserting that environmental innovations imply higher interdependencies with external partners, both to conceive and finalize the products and to gain green profits in the market. To gain further insight into the role of cooperation strategies, I analyzed the role of different typologies of partners. Results indicate that vendors are very important partners, corroborating the presence of technological interdependencies on knowledge, skills and resources that arise in the development of environmental innovation. Similarly, scientific agents are more important partners than for other innovations. The complexity of products' impact on the environment and the knowledge-intensive competencies required to handle some sustainability issues may induce firms to rely to a greater degree than for other innovations on cooperation with universities and public or private research centers. Conversely, coefficients regarding cooperative agreement with customers were never significant. This result does not deny the cornerstone contributions of Von Hippel and others on the relevance of lead users in the innovation process (Von Hippel, 1986; von Hippel, 1976), but simply reports that users are not more important partner for environmental than for other innovations. This result should not be surprising: environmental features are often not easily detectable by end users (Darby and Karny, 1973; Andersen, 1999) and may require very sophisticated technical knowledge.

My results indicate that environmental innovators diverge for the implementation of continuous R&D rather than for the relative amount of resources dedicated to internally research and develop new ideas and products, similarly to that detected in Horbach's analysis of German manufacturing firms. Moreover, I provide support for the presence of a substitution effect between internal R&D activities and cooperation with external partners. This evidence is in line with results of the general innovation literature (see e.g., Laursen and Salter, 2006; Vega-Jurado, Gutierrez-Gracia, and Fernandez-de-Lucio, 2009), yet contradicts the scant empirical evidence regarding environmental innovations (Mazzanti and Zoboli, 2005). However, results could have been different if it would have been possible to detect the amount of resources dedicated specifically to *environmental* R&D rather than to the *overall* R&D, which is the case in the analysis of Mazzanti and Zoboli. Further research in this area is needed, in order to understand the sign of the relationship between internal R&D and cooperation toward eco-innovation.

Serving an international market proved to be significantly correlated with green innovation; however, the sign of the relationship is negative: localization matters when trying to gain green profits in the market. The absence of uniquely recognized standards defining green features together with the fact that often "green issues are credence characteristics which are not apparent from the products " (Andersen, 1999) add to the importance of trust, reputation and direct communication efforts, which may be more easily acquired through proximity to the final market.

5.1 Limitations and Further Research

The analysis of CIS datasets is useful to gain knowledge on a large number of observations yet has some limitations, as these datasets are not built to assess specifically green innovation nor to evaluate the nature of relations with external partners. The variables used to measure cooperation do not allow for an analysis of the intensity of cooperation and the size of the network. This analysis should then be complemented by in-depth studies and observational research, investigating the typology of governance that characterizes the relationship, firm's strategies and appropriability concerns. Similarly, the identification of environmental innovation may be improved by the use of a different dataset or through qualitative analysis. Future research should address also differences in the typology of green innovations. Very little is known of the differences among green products and process (del Río González, 2009). Although product and process innovations have proved to be very often complementary and introduced simultaneously (Reichstein and Salter, 2006), they may require a different degree of cooperation and imply different appropriability strategies. Moreover, a comparative analysis between radical and incremental innovations would be extremely valuable, on the one hand to contribute to the debate on the radicalness of green innovations (e.g., Hellstrom, 2007) and on the other to understand the heterogeneities of cooperation strategies.

Another limitation of this study, posed by its empirical set, is that it does not distinguish between B2B and B2C industries, which may shed light, for example, on the role of users on environmental innovation.

Future research should address these topics at a value chain level, rather than just on a dyadic one, to more thoroughly understand environmental innovation dynamics. The literature on Green Supply Chain Management reveals that, to gain green profits in the market, firms have to assure the environmental performance of the entire value chain and cooperate with more upstream partners than just first-tier suppliers (Seuring, 2004; Seuring and Müller, 2008).

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Appendix

Table 6: First Part 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.

Table 7: 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	1.000								
p-value	*0.000*									
3.R&D_INTENSITY	0.140	0.036	1.000							
p-value	*0.000*	*0.005*								
4.CONT_R&D	0.242	0.040	0.364	1.000						
p-value	*0.000*	*0.002*	*0.000*							
5.SIZE	0.124	0.096	-0.282	0.186	1.000					
p-value	*0.000*	*0.000*	*0.000*	*0.000*						
6.EXPORT	0.097	0.076	0.028	0.249	0.295	1.000				
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	1.000			
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	0.010		
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	1.000	
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	1.000
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*