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A resource pool for environmental innovation

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Abstract

This paper reports research on the relationship between sourcing strategy of a firm and its environmental innovation propensity. The data is taken from the Spanish Technological Innovation Panel (PITEC) survey during the period of 2007-2011. The uniqueness of the Spanish innovation structure and the increasing relevance of environmental issues for the Spanish economy make it a proper setting to investigate environmental innovation dynamics. The results from 5,352 firms indicate that large firms are more likely to undertake environmental innovation than small- and medium-sized firms (SMEs). These firms rely quite equally on all four sources of knowledge – internal, market, institutional and freely-available sources – when deciding to develop environmental innovation. The broad horizons with respect to knowledge sources are likely to increase firms' propensity to introduce environmental innovation. In addition, we provide the evolutionary nature of firm's innovation search as firms grow in size. Small firms rely on both internal and freely-available sources rather equally, while internal source is the most relevant for medium firms, and market is the most important source used by large firms in driving environmental innovation. Particularly important is how firms who are already innovators and who receive local funding from the Spanish government are more likely to introduce environmental innovation.

Keywords: environmental innovation, knowledge sourcing, discrete choice model

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Introduction

The concern for the environment has brought about increasing pressure on mankind to preserve and maintain natural resources (Bilbao-Osorio et al., 2012; Elkington, 1994). This has led to various developments of environmental laws, policies and programs in recent years such as Clean Air Act, ISO14001, tradable emissions, or United Nations Environment Program (UNEP). It is now becoming increasingly clear that business should play a role in achieving these greening goals (Elkington, 1994; Johnstone, Hascic, & Ostertag, 2008) and since one of the mechanisms for firms to deal with the changing environment is through innovations (Schoonhoven, Eisenhardt, & Lyman, 1990), environmental innovation therefore presents itself as an effective and indispensable solution to respond to this mounting pressure and changing environment (De Marchi, 2012; Johnstone et al., 2008).

The purpose of this paper is to extend traditional innovation literature on search strategy, into environmental innovation context. Though innovation is a risky business, firm's success indeed depends on its ability to innovate consistently (Rosenkopf & Nerkar, 2001). Also, the fact that the development of firm's core knowledge is inextricably linked to its search strategy that shapes firm's innovation (Katila & Ahuja, 2002) and plays an important role in helping firms to create and sustain competitive advantage overtime (Eisenhardt & Martin, 2000). A study on search strategy warrants a detailed study. Greek myth has goddess of wisdom, Athena, bursts fully-grown from Zeus' head, but firms' knowledge does not aborn in one instance like Athena (Leonard-Barton, 1995). No wonder 'learning organizations' are lauded for their ability to generate, source, acquire, and integrate different sources of knowledge (Nonaka & Takeuchi, 1995; Rosenkopf & Nerkar, 2001). We are interested in studying the relationship between knowledge sourcing and firms' propensity to introduce environmental innovation. We empirically examine different sources – namely market sources, internal sources – firms employ as inputs into their decisions to develop environmental innovation. One important aspect within the management of innovation is the optimal integration of different types of knowledge sources (Leiponen & Helfat, 2010); hence, we also examine the effect of breadth of types of knowledge sources on environmental innovation.

Indeed, numerous papers have addressed the relationship between environmental issues and firms, such as how to develop proactive environmental strategy (Aragón-Correa & Sharma, 2003) or benefits from operating in an environmentally-friendly manner (Bansal & Clelland, 2004). However, innovation with respect to environment per se has not yet been analyzed in sufficient depth, principally due to unavailability of data (Toshi, Hibiki, & Johnstone, 2007). The paper contributes in several important ways.

First, we help shed light on the nature of environmental innovation search, specifically, on where firms seek knowledge from during their search process and the importance of each knowledge source, whether they are small or big firms, new or old, or in the manufacturing or service industries. In this regard, we offer an insight into the evolutionary nature of firms' reliance on different sources of knowledge as they grow from small to big and new to old. As yet, few attempts have been made to theoretically and empirically link firms' search strategy with environmental innovation. Basically, empirical analyses on any types of driving forces of environmental innovation whatsoever are still rare (Chang, 2011; Horbach, 2008).

Second, we add to the field by analyzing not just one type of knowledge source, but different types of knowledge sources together. Such study provides the opportunity to not only examine the different search strategies firms employ, but also to assess the degree of openness of firms' search strategies, or as we call 'breadth' in this paper. To our knowledge, rarely are several types of knowledge sources are compared simultaneously.

Third, our data spans forty four industries. We are not confined to one single sector study or on small samples of particular industries like most previous works in search strategy literature (Laursen & Salter, 2004). Furthermore, the existing literature is largely based on patent analysis, which provides an incomplete perspective on innovation. Patents vary in economic importance across sectors (Laursen & Salter, 2004) and particularly patent data is still not an effective mean to measure environmental innovation (Toshi et al., 2007). As we are not using patent data, we surmount this limitation and provide intelligence into environmental innovation issue from another perspective.

Lastly, previous studies mainly provide a small sample analysis of listed firms or of specific industry, particularly the environmental goods and services industry (Kemp & Pearson, 2007).Our study, on the contrary, is based on a large scale dataset of over 5,000 observations, ranging from local micro-firms to very large multinational companies. In doing so, we could expand the literature into other types of firms and other industries.

To date, the terms eco-innovation, environmental innovation and green innovation have been used synonymously (Tietze, Schiederig, & Herstatt, 2011). In this paper, we adopt the definition below.

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

We examine the relationship between different sourcing strategies and environmental innovation using a PITEC survey of 5,352 Spanish firms during 2007-2011. Spain is considered a moderate innovator (Hollanders & Es-Sadki, 2013) with 1.45% gross domestic expenditure on R&D in 2010 versus 2% of the EU average (Eurostat, 2013), yet Spain is very advanced in terms of environmental innovation, being among one of the top in the world (Barranco, 2013). In this manner, Spain provides an interesting context to study environmental innovation.

The remainder of the paper is organized into four parts. Part two focuses on the literature explaining the relationship between knowledge sources and environmental innovation. In Part three, we present the data, and in Part four, we analyze the results. Part five concludes.

Literature review and hypotheses

We draw on innovation sourcing literature to examine the link between knowledge sourcing and environmental innovation.

Where do firms get producing inputs to make decisions to develop green innovation?

According to a prevalent model of technological change by Griliches (1979), innovative output is the product of knowledge generating inputs. A successful innovation depends on how successful firms are at identification of, deliberate search for, reaching out to, managing and implementing these promising sources (Cohen & Levinthal, 1990; von Hippel, 1988).

Internal knowledge offers a number of advantages over the reliance on outside research and development, particularly when aspects of relevant knowledge needed to develop innovation is tacit and somewhat idiosyncratic (Nelson, 1986). With an inward focus, firms focus on similar technology previously developed and become experts in their current technological domains (Dosi, 1988). On the other hand, firms' ability to detect and exploit outside knowledge proves to be critical to the innovation processes (Leiponen & Helfat, 2010). They gain ideas for innovating from a wide variety of different sources (Cohen & Levinthal, 1990; Laursen & Salter, 2004). For instance, firms can draw knowledge from customers and users (von Hippel, 2009), suppliers (Leiponen, 2002), competitors (Cassiman and Veugelers, 2006), public research (Cohen, Nelson,

& Walsh, 2002) such as from universities (Laursen & Salter, 2004) or freely-available information (Veugelers & Cassiman, 1999).

Empirical evidence shows that knowledge from and cooperation with suppliers are important for the development of environmental innovation, especially to ensure eco-friendly features of the inputs (De Marchi, 2012). Exchanges of information with customers also prove to be a key to help firms reach their environmental targets (Theyel, 2006). We thus propose the following hypothesis:

> *Hypothesis 1: Firms that draw knowledge more from internal and market sources are more likely to decide to introduce environmental innovation than firms that draw knowledge more from institutional or freely-available sources.*

And the relation with size

Not only that firms of different sizes behave differently in terms of innovation and face different innovation-related circumstances (Busom, Martinez & Corchuelo, 2011), but also they employ different search strategies. They exhibit changes in the way they organize, reorganize, outsource and/or shift the origin of their knowledge creation (Laursen & Salter, 2004). We expect small firms to draw more from institutional sources such as from universities or public research. As most research in this field is still concentrated in the public sector (Horbach, Oltra & Belin, 2013), it is only natural that firms look to these institutions for ideas more than from other sources. Findings by Jaffe (1989) and Acs, Audretsch and Feldman (1994) show that spillovers from university research laboratories are more important in producing innovative activity in small firms than in large firms. Small firms, particularly small start-ups, are often viewed as key vehicles transferring university research into commercial innovation, and they draw knowledge more from public research (i.e., universities and government R&D labs) (Cohen et al., 2002).Small firms are certainly capable of being the engine of innovative activity despite their obvious lack of formal internal R&D activities (Kleinknecht 1987).

Furthermore, we also expect small firms to draw rather equally from freely-available sources. Cohen et al. (2002) suggest that the most important channels for firms to access public research, or as we call it institutional source in this paper, are through publications and conferences rather than licenses or cooperative ventures. Small firms are confronted with limited resources and faced with internal shortages of information (Lu & Beamish, 2001). The standard practice to move knowledge across firm boundaries often involves contractual agreements (Rosenkopf & Nerkar, 2001) that can be costly for these small firms. Drawing from freely-available sources presents itself as an appropriate strategy because it does not incur or incur little costs and complements the lack of internal knowledge.

For medium firms, we expect them to draw more on internal knowledge. As the size becomes bigger, these medium-sized firms start to be able to afford internal R&D, conduct more R&D and be involved in more R&D projects (Cohen et al., 2002). Internalized corporate search allows firms the ability to exploit the future cumulativeness and the complexity of technological knowledge as well as helping to reduce the uncertainty of innovative search without eliminating the chance to innovate (Dosi, 1988). Individuals inside firms are unable to consider the universe of all possible options due to bounded rationality. They look to firms' previous developments for guidance (Stuart & Podolny, 1996). In the context of high ambiguity and uncertainty as in environmental innovation context, firms' past researches are natural starting points for new innovations (Nelson & Winter, 1982). Moreover, internal R&D provides firms with the capability to both develop new products and processes as well as to absorb knowledge from outside the firm (Cohen & Levinthal, 1990). Even under circumstances where collaborative effort with external actors is required, it is thought essential that firms develop internal competencies first in order to be able to facilitate the effective recognition, appraisal, negotiation and assimilation of external expertise (Dosi, 1988). After all, in most industries, the greater part of the innovation effort is made by the firms themselves (Gassman, 2006; Solow, 1957) and medium firms can indeed successfully innovate without any external collaborations (Freel, 2003).

Larger firms are the ones who are more responsive to the changes in their industry R&D than smaller firms (Acs et al., 1994). Because larger firms, often with broader sets of innovation projects, have a wider spread of knowledge base, they are better apt at absorbing and exploiting complementarities from external sourcing (Laursen & Salter, 2004; Veugelers & Cassiman, 1999). Many times, larger firms simply buy their smaller-sized competitors in order to obtain their knowledge (Arora & Gambardella, 1990). Besides, technology outsourcing creates considerable costs, ex ante in terms of search and ex post in terms of execution and enforcement (Veugelers & Cassiman, 1999). We expect larger firms to be the ones who are able to afford this option more than their smaller counterparts.

For environmental innovation that is still largely unknown to most firms (Horbach et al., 2013), it will not be surprising if these firms form strategic alliances or joint ventures with suppliers and competitors. Firms can also work closely with customers, or even hire consulting firms, notably the ones who are specialized in environmental compliance or sustainability.

Our hypotheses are as follows:

> *Hypothesis 2: Small firms are more likely to draw knowledge from freely-available sources than from other sources when deciding to introduce environmental innovation.*
>
> *Hypothesis 3: Medium firms are more likely to draw knowledge from internal source than from other sources when deciding to introduce environmental innovation.*
>
> *Hypothesis 4: Large firms are more likely to draw knowledge from market sources than from other sources when deciding to introduce environmental innovation.*

And the relation with the intensity of sources of knowledge used

Since Solow's work in 1957, researchers and practitioners alike have been associating strong internal knowledge with innovativeness (Gassman, 2006). However, prior research also argues that myopic behavior of narrow search from only within firms leads to potential developments of 'competency traps' (Levitt & March, 1988) and/or 'core rigidities' (Leonard-Barton, 1995). Gains associated with internal technology development alone are not sustainable unless firms integrate outside knowledge (Rosenkopf & Nerker, 2001). As a consequence, a wider and more diverse search create more opportunities to access and integrate knowledge sets (Katila, 2002; Nelson & Winter, 1982). Because innovation often results from knowledge fusion or novel recombination from several sources (Kogut & Zander, 1992), pursuing breadth of knowledge helps to increase the odds of innovation success.

For environmental innovation that is riskier, requires greater financial commitment than traditional innovations (Berrone, Fosfuri, Gelabert & Gomez-Mejia, 2013) and is still relatively new and unknown (Horbach et al., 2013), similar logic could be applied and may be needed even more so than the case of traditional innovations. Our key assumption is that a diverse search could help ready firms for environmental innovations. Breadth of knowledge would warrant firms with a vast supply of knowledge inputs to develop innovation with eco-friendly features. Particularly in a context where there exists a high uncertainty about which knowledge domain would provide potentially useful information, broad and simultaneous search could help firms hedge against uncertainties, ensuring that at least one of the sources would lead to environmental innovation. Knowledge diversity provides not only a more robust basis for learning, but also interactions across different knowledge sources would help augment firms' ability in making novel linkages and associations beyond the reliance on a single source alone (Cohen & Levinthal, 1990). In order to examine this question, we develop a proxy variable for 'breadth' of a firms' innovation search strategy. The variable is based on the number of different sources of knowledge each firm draws on in its innovative activities. The foregoing arguments suggest the following hypothesis:

> *Hypothesis 5: The higher the level of breadth of knowledge sources the individual firm draws from, the more likely it will develop environmental innovation.*

Data and statistical reference

Data and Empirical Setting

The empirical setting in this study is Spanish firms. The data is taken from Spanish Technological Innovation Panel (PITEC) survey[3]. It 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 choice for this dataset is multifold. First, PITEC is one of the very few large-scale surveys that provides usable data on environmental innovation. Second, PITEC is based on the Community Innovation Survey (CIS) framework, which is a valid tool in studying innovation and is one of the most used datasets for studying innovation (Laursen & Salter, 2004, 2006). This enables direct comparisons of this work with previous empirical literature as well as future research using similar datasets. Finally, the uniqueness of the Spanish innovation structure and the increasing relevance of environmental issues for the Spanish economy (De Marchi, 2012) make it a proper setting to investigate environmental innovation dynamics. Spain is considered as a moderate innovator (Hollanders & Es-Sadki, 2013). The gross domestic expenditure on R&D was 1.45% in 2010 versus 2% of the EU average (Eurostat, 2013). In terms of the overall innovation performance based on the Innovation Union Scoreboard 2013 by the European

[3] The dataset, the questionnaire and the description of each variable is available free of charge at the website http://icono.fecyt.es/PITEC/Paginas/por_que.aspx

Commission, Spain also under-performed with respect to other EU 27 countries, scoring 0.41 versus 0.54 (Hollanders & Es-Sadki, 2013). However, Spain is aiming towards more environmental innovation to help boost its economic growth. Spanish green patent applications have grown the most, among others of China, India, Italy and Japan, between 2000 and 2009 (Barranco, 2013).

Given the lack of data availability at a project level, we study environmental innovation at a firm level. Though PITEC has been administered since 2003, the changing nature of the sample and of PITEC questionnaire poses challenges for inter-temporal analyses. In addition, data on environmental innovation is available only in a block of period, not yearly. We therefore are restricted to cross-sectional methodology.

In 2007, the response rate was 90.60%. At present, PITEC sample contains about 13,000 firms and comprises four sub-samples. The first sub-sample is composed of firms with 200 employees or more while the second represents firms with internal R&D expenditures. In 2004, two more sub-samples were included. They are firms with less than 200 employees who report external but no internal R&D and the last sub-sample is firms with no innovation expenditures. The degree of representativeness of the population depends on the size of the company. While it is representative for the firms with more than 200 employees, the representativeness of firms with less than 200 employees are biased towards firms having internal and/or external R&D. About 74% of firms in the sample claim to innovate. They are identified by their answer to the question regarding whether or not they have introduced innovation in the previous two years.

We combine PITEC survey for the period of 2009-2011 with PITEC survey for the period of 2007-2009. The former contains our dependent variable while the latter contains our explanatory and control variables. The two-year overlap helps to alleviate simultaneity issue as well as to reduce the potential problem of common method variance (Podsakoff & Organ, 1986) and endogeneity. Nevertheless, we check for common method variance using Harman's one-factor test. We perform factor analysis on all variables using unrotated factor analysis and principal component analysis with and without varimax rotation. The results suggest no potential problem of common method variance. No single factor emerges and no factor accounts for a majority of variance (with 36% for the first factor). Our effective sample consists of 5,352 firms from forty-four industries.

Dependent variable

To measure environmental innovation, we follow the approach of De Marchi (2012) in using self-report data on the objectives of the innovation introduced. Kemp and Pearson (2007) suggest using this method to measure environmental innovation, rather than using environmental investments (input) or environmental patents (output) that have been extensively employed (Nameroff, Garant, & Albert, 2004). Using environmental R&D presents problems as this proxy could lead to over- or under-estimation of innovation (De Marchi, 2012). Further, allocation of expenditures for specific objectives is determined by managers; however, drawing the exact boundaries between different objectives is by no means straightforward (Grupp, 1998). The use of green patents also raises methodological issues (Toshi et al., 2007). There is no widely accepted agreement in the literature yet as to what constitutes environmental technology and the patent classification system does not provide specific categories for environmental patents. The identification of green patents is based solely on researchers' judgments and understandings (Kemp & Pearson, 2007). As a consequence, one may argue that the use of objective is not inferior to the use of environmental R&D or environmental patents.

To construct our dependent variable, we utilize questions of PITEC survey that ask about the importance of the following objectives for their innovations: (1) using less material per one unit produced; (2) using less energy per one unit produced; (3) lower impact on the environment; and (4) complying to the requirements on environment, health and security. The survey asks each firm to evaluate the importance of each objective based on a Likert scale of 1 to 4, with 4 as null and 1 as very important. We first assign binary values for each objective. A response of 1 (very important) or 2 (important) receive a binary value of 1, where responses of 3 (some importance) and 4 (null) receive a binary value of 0. We then aggregate these answers and rescale the total score into 0 and 1, with firms having 0s across all four objectives as 0, and 1 otherwise. About 76% of firms in the sample are environmental innovators. The use of binary values is preferred as it helps to alleviate potential measurement error. In addition, binary values help to reduce the problem where the ordinal nature of Likert scale cannot be interpreted as interval scale (Leiponen & Helfat, 2010). The use of a dummy as a dependent variable also allows comparing the emerging evidence with existing literature (De Marchi, 2012, Horbach, 2008).

Unfortunately, PITEC is not specifically designed to investigate green innovation per se. This variable thus could be criticized. To mitigate the potential problem, we employ different specifications for our dependent variable, testing the robustness of the model.

Explanatory variables

The key explanatory variables in our study represent different sources of knowledge and breadth of knowledge sources firms utilize in their innovation activities. PITEC asks respondents to identify the importance of each of the sources of information used in innovation activities. The survey lists altogether eleven different sources of information for innovation, listed in Table 1.

TABLE 1: Knowledge sources

	Sources	Mean	s.d.
Internal	Own firm (within the firm and/or group)	0.86	0.35
Market	Suppliers	0.59	0.49
	Customers	0.60	0.49
	Competitors	0.42	0.49
	Consulting firms, private research institutes	0.36	0.48
Institutions	Universities or other higher educational centers	0.29	0.45
	Public research institutes	0.21	0.41
	Technology centers	0.30	0.46
Freely-available	Conferences, trade fairs, exhibitions	0.43	0.50
	Scientific journals and trade/technical publications	0.38	0.48
	Professional associations	0.28	0.45

To construct variables for different types of knowledge sources, we adopt the approach used in Leiponen and Helfat (2010)'s paper. We assign a response of 1 (very important) or 2 (important) to a binary value of 1, and a response of 3 (some importance) and 4 (null) to a binary value of 0. To simplify the model and to account for potential overlap among knowledge sources, we group knowledge sources into broader categories. The first type of knowledge source remains as it is and it represents an internal source. The next four are grouped into market sources, the next three into institutional sources, and the three remaining sources into a fourth category of freely-available sources. These represent external knowledge sources. We follow Veugelers and Cassiman (1999)'s approach when aggregating different sources together: summing binary scores on related variables and rescale the total score to a 0 and 1.

To construct a variable indicating breadth of knowledge sources, we follow the approach other researchers (Laursen & Salter, 2006; Leiponen & Helfat, 2010) have used with CIS data. We sum binary values of the eleven sources together. This variable has a maximum value of eleven. The mean value is 4.72.

Control variables

Firm type: listed, private or institutes. Firms that are listed face more pressure to be environmentally friendly due to transparency and visibility of being listed; nonetheless, being listed facilitates easier access to capital to finance environmental innovation (Toshi et al., 2007). Consequently, we include dummies of private firms, listed firms, or institutes as controls. For private firms, we control for (1) private firms with no foreign capital, (2) private firms with foreign capital less than 10%, (3) private firms with foreign capital between 10-50%, and (4) private firms with foreign capital more than 50%.

Size. Size has been found to affect environmental innovation propensity. Smaller firms are found to have difficulties in finding investments needed to switch to greener technologies and in dealing with complexities of environmental innovation (Toshi et al., 2007). Firm size is included through three dummies: small (1-50 employees), medium (51-200 employees) and large (more than 200 employees).

Innovation effort. Cassiman and Veugelers (2006) find that higher innovation expenditure, controlling for size, increases firms' likelihood to engage in innovation activities. The size of the firms in our sample varies from 1 to 40,504 employees so using R&D intensity would be more appropriate than using the actual amount spent on R&D. We extend from traditional innovation literature and use the same approach of using the natural log of total innovation expenditures divided by total sales to control for R&D intensity, or firms' previous innovation effort from 2007-2009, for environmental innovation context.

Innovation output. Serial innovators are more likely to introduce green innovation (De Marchi, 2012, Horbach, 2008). The variable 'product innovation' gets the value of 1 if firm reports to have introduced product innovation during 2007-2009.

Funding. We include dummies reflecting public support to innovate; valuing 1 if firms have received public support in the form of subsidies for innovation purposes during the period of 2007-2009. Policymakers have been using a market-based instrument such as subsidies to stimulate development and diffusion of environmental technologies (Rennings, 2000). We control for both local funding from the Spanish government and European Union-level funding.

Industry dummies. It is necessary to control for industry differences. Level of R&D for environmentally-related innovation differs by industry type (Toshi et al., 2007). Demands and technological opportunities along with consumers' awareness and policy restrictions concerning environments also vary across sectors (De Marchi, 2012; Toshi et al., 2007). We hence include forty-four industry dummies in our model.

We would like to include a control of firm's environmental performance, as suggested by previous literature (Lázaro, Dorronsoro, Casas, Rodríguez, & Sedano, 2008). This control variable could be a dummy of whether or not a firm is ISO14001 certified, EMAS registered, has environmental reports, or the like. Unfortunately, PITEC data is anonymized. We could not complement the dataset with externally-obtained information.

Table 2 presents the definitions of our variables and some descriptive statistics.

TABLE 2: Variable definitions

Variables	Description	Mean	s.d
Environmental innovation	Environmental innovation	0.65	0.48
	- Less material	0.40	0.49
	- Less energy	0.40	0.49
	- Lower impact on the environment	0.49	0.50
	- Compliance to environmental, health and security requirements	0.50	0.50
Internal	Importance of internal information as sources for the innovation process.	0.86	0.35
Market	Importance of markets as sources for the innovation process.	0.84	0.40
Institutions	Importance of institutions as sources for the innovation process.	0.42	0.49
Free	Importance of other sources as sources for the innovation process.	0.55	0.50
Breadth	Breadth of sources of knowledge (0-11)	4.72	2.85
Listed	Listed firm	0.02	0.15
Private (local)	Private firms with no foreign capital	0.79	0.41
Private (<10%)	Private firms with foreign capital less than 10%	0.02	0.13
Private (10-50%)	Private firms with foreign capital between 10-50%,	0.02	0.15
Private (>50%)	Private firms with foreign capital more than 50%	0.13	0.33
Institutes	Institutes	0.02	0.14
Small	Small firm of 1-50 employees	0.47	0.50
Medium	Medium firm of 51-200 employees	0.28	0.45
Large	Large firm of more than 200 employees	0.25	0.43

R&D intensity	Natural log of Total innovation expenditure/total sales	-3.53	1.94
Product Innovation	The firm has introduced product innovation during the period 2007-2009	0.74	0.44
Local funding	Receive Spanish public funding (subsidies)	0.45	0.50
EU funding	Receive public funding (subsidies) from the EU	0.07	0.25
Parent	Parent company	0.23	0.42
Subsidiary	Subsidiary of another firm	0.67	0.47
JV	Joint venture	0.03	0.16
Partnership	Partnership	0.08	0.27
Industry	44 industries as according to CNAE 2009		

Results

Table 3 reports correlation coefficients. The correlations between different sources of knowledge and environmental innovation are positive and significant. The correlation between breadth of knowledge sources and environmental innovation is positive and significant ($r = 0.22$, $p < .05$). All the different types of sources of knowledge are also positively correlated to each other. Concerning control variables, only research institutes are positively correlated with environmental innovation ($r = 0.05$, $p < .05$), while negatively correlated for listed firms ($r = -0.03$, $p < .05$). Small firms are negatively correlated with environmental innovation ($r = -0.09$, $p < .05$) while medium and large firms are negatively correlated ($r = 0.05$, $p < .05$; $r = 0.07$, $p < .05$). It is interesting to note that R&D intensity (1) does not correlate with environmental innovation or listed firms; (2) positively correlates with small firms ($r = 0.05$, $p < .05$); and (3) negatively correlates with large firms ($r = -0.04$, $p < .05$). Both Spanish and EU subsidies correlate positively with environmental innovation ($r = 0.12$, $p < .05$; $r = 0.04$, $p < .05$, respectively). Firms that introduced innovation in the previous two years are positively correlated with environmental innovation ($r = 0.15$, $p < .05$). The correlations indicate low probability of multicollinearity problem. Nonetheless, we further verify using Collin command in Stata. The variance inflation factors (VIFs) are in the range of 1.07-2.20 with the mean of 1.38, indicating no evidence of multicollinearity.

TABLE 3: Correlation coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Environmental innovation	1															
2. Internal	0.15*	1														
3. Market	0.16*	0.35*	1													
4. Institutions	0.15*	0.16*	0.21*	1												
5. Free	0.16*	0.22*	0.33*	0.31*	1											
6. Breadth	0.22*	0.41*	0.54*	0.62*	0.70*	1										
7. Listed	-0.03*	-0.03*	-0.03*	-0.04*	-0.00	0.01	1									
8. Private	-0.01	0.00	-0.01	-0.12*	-0.06*	-0.12*	-0.72*	1								
9. Institutions	0.05*	0.03*	0.04*	0.13*	0.09*	0.16*	-0.02	-0.68*	1							
10. Small	-0.09*	-0.06*	-0.03*	-0.02	0.01	-0.04*	-0.08*	0.04*	0.03*	1						
11. Medium	0.05*	0.03*	0.01	0.03*	0.02	0.03*	-0.03*	0.01	0.02	-0.59*	1					
12. Large	0.07*	0.04*	0.02	-0.00	-0.03*	0.02	0.13*	-0.06*	-0.05*	-0.54*	-0.36*	1				
13. R&D intensity	0.01	0.05*	0.06*	0.21*	0.15*	0.21*	0.01	-0.20*	0.26*	0.40*	-0.09*	-0.37*	1			
14. Product innovation	0.15*	0.15*	0.18*	0.10*	0.18*	0.21*	-0.03*	0.02	0.01	-0.00	0.04*	-0.04*	0.13*	1		
15. Local funding	0.12*	0.13*	0.15*	0.38*	0.17*	0.31*	0.03*	-0.11*	0.13*	-0.01	0.03*	-0.01	0.32*	0.13*	1	
16. EU funding	0.04*	0.04*	0.07*	0.19*	0.10*	0.18*	0.12*	-0.26*	0.25*	-0.04*	0.00	0.04*	0.22*	0.03*	0.21*	1

*$p < .05$

Test of hypotheses

We use probit model to regress our measure of environmental innovation on sources of knowledge and breadth of knowledge, together with firm level characteristics, innovative capabilities and industry dummies controls.

Table 4 reports results of hypotheses 1-5, testing the relationships between four different sources of knowledge and environmental innovation. Column (I) reports the coefficients and marginal effects of the full model, testing hypothesis 1. The result testing hypothesis 5 is reported in Column (II), investigating the impact of breadth of knowledge sources on environmental innovation propensity. The results of hypotheses 2-4 are reported in Column (III), (IV) and (V), testing the relationships run on different sub-samples based on firm size: small (1-51 employees), medium (51-200 employees) and large (more than 200 employees), respectively.

TABLE 4: Regression results for knowledge sources

	(I) Full model		**(II) Breadth**		**(III) Small**	**(IV) Medium**	**(V) Large**
	β	**ME**	**β**	**ME**	**ME**	**ME**	**ME**
Internal	0.2477**	0.0875**			0.0945**	0.0940*	0.0744†
Market	0.2544**	0.0898**			0.0524†	0.0842*	0.1520**
Institutions	0.1661**	0.0586**			0.0829**	0.0192	0.0710*
Free	0.1980**	0.0699**			0.0868**	0.0750**	0.0393
Breadth			0.0823**	0.0290**			
Controls:							
Private (local)	0.1933	0.0716	0.2132	0.0791	0.1080	0.2160†	0.0487
Private (<10%)	0.2325	0.0855	0.2119	0.0786	0.1136	0.3755**	-0.0681
Private (10-50%)	0.2126	0.0785	0.2234	0.0827	0.2207†	0.1442	-0.0133
Private (>50%)	0.2915*	0.1057*	0.3104*	0.1128*	0.1357	0.2450†	0.0528
Institutes	0.5102*	0.1746*	0.4887*	0.1696*	0.2424†	0.2455	0.2067†
Medium	0.1538**	0.0543**	0.1494**	0.0527**			
Large	0.3803**	0.1343**	0.3766**	0.1328**			
R&D intensity	0.0507**	0.0179**	0.0512**	0.0180**	0.0090	0.0204*	0.0200*
Product innovation	0.2794**	0.0987**	0.2853**	0.1006**	0.0960**	0.0993**	0.0753*
Local funding	0.1160**	0.0410**	0.1102**	0.0389**	0.0321	0.0296	0.0622*
EU funding	0.0007	0.0003	-0.0169	-0.0060	-0.0372	0.0644	0.0554
Industries	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Predicted probabilities		71.17%		70.82%	68.04%	74.29%	76.60%
N	5339	5339	5339	5339	2478	1517	1316

Probit model:

Log likelihood	-3010.32	-3009.65	-1495.32	-820.29	-638.86
LR Chi2 (50)	731.31**	732.65**	293.89**	198.85**	278.23**
Pseudo R^2	10.83%	10.85%	8.95%	10.81%	17.88%

†$p < .10$, *$p < .05$, **$p < .01$

Note: the β column reports coefficients, while the ME column contains marginal effects of the coefficients calculated at means.

The results from Column (I) show that the marginal effects of internal and market sources are significant and higher than institutional and freely-available sources, supporting hypothesis 1. The signs of most of the coefficients of the controls are as expected. Larger firms are 13% more likely to develop environmental innovation, in comparison to medium-sized firms and small firms, while medium firms are 5% more likely. Firms that have previously developed innovation display a stronger likelihood to introduce environmental innovation. Local funding, rather than EU funding, even in the form of subsidies, still are likely to encourage firms to develop environmental innovation. Surprisingly, there are only few manufacturing industries that are likely to develop environmental innovation. They are food and drinks, chemicals, plastics. Service industries such as transport, information and communication services and other auxiliary services, on the contrary, are unlikely to develop environmental innovation. The model correctly predicts 71.17%.

The results from Column (II) support hypothesis 5. The higher the level of breadth of knowledge sources employed by individual firm, the more likely it will develop environmental innovation, compared to other firms with lower level of breadth.

Concerning the different sub-samples, Column (III) shows that the decisions of small firms to develop environmental innovation depends more on internal knowledge and rather equally on institutional and freely-available sources, not supporting hypothesis 2. For medium-sized firms, the marginal effect of internal source is the highest among the four knowledge sources. Hypothesis 3 is supported. Large firms relying on market sources are 15% more likely to develop environmental innovation, compared to other types of knowledge sources employed, confirming hypothesis 4.

We further break down our size from three subsamples into six subsamples, with small firms breaking down into three subsamples of 1-10, 11-25 and 25-50; medium firms remain the same; and large firms into two subsamples of 201-500 and more than 500 employees. In Figure 1, an evolution of the usage of the different types of knowledge sources emerges as firms grow from small to large. When we break down the size in this manner, our hypothesis 2 is actually supported. With Figure 1, we also illustrate the differences in the sourcing strategies of firms belonging in manufacturing or service industries as well as new (of up to 10 years old) or old firms.

FIGURE 1: Sourcing strategies of firms of differing Size, industry and age

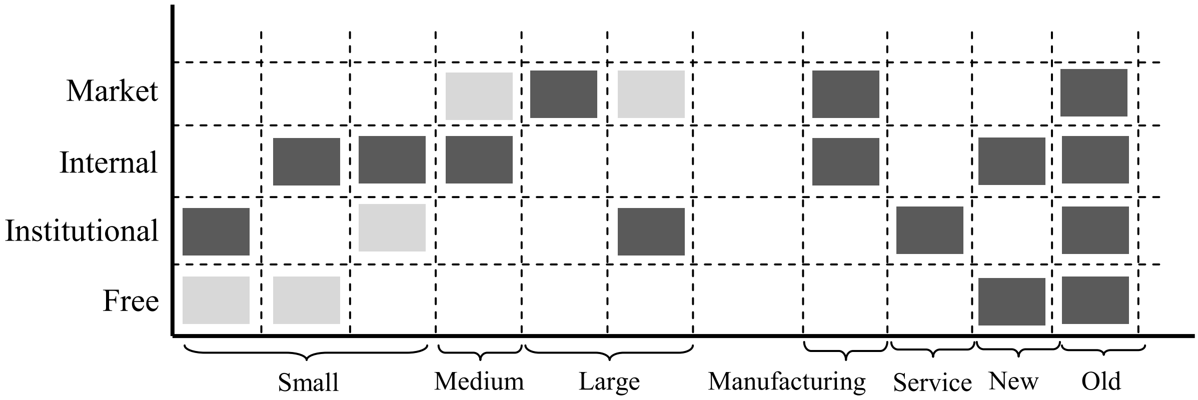

Table 5 reports marginal effects using another specification of the dependent variable. Instead of using the aggregate of the four different innovation objectives with environmental goals, we regress on individual objective. Again, we use the same method described above to rescale a Likert scale of 1-4 (very important to null) into binary values. Column (I) reports results with the objective of using less material per one unit produced as a dependent variable. Column (II) reports results concerning the objective of using less energy per one unit produced. Column (III) and (IV) report results concerning the objectives of lowering the impact on the environment, and complying with the requirements of environment, health and security, respectively. These results do not change the results of our full model in Table 4. Instead these results further give us insights into the breakdown of the relationships between each source of knowledge and each environmental innovation objective. For reduction of material and energy usage, firms rely on market sources more than other sources of knowledge when developing environmental innovation. For the objectives of reducing environmental impact and complying with environmental requirements, firms rely more on internal knowledge than other sources.

TABLE 5: Regression results for individual environmental innovation objective

	(I): Material	(II): Energy	(III): Impact	(IV): Compliance
Internal	0.0831**	0.0643**	0.1229**	0.1045**
Market	0.1046**	0.1054**	0.0771**	0.0650**
Institutions	0.0335*	0.0318*	0.0905**	0.0537**
Free	0.0672**	0.0674**	0.0937**	0.1026**
Controls:				
Private (local)	Yes	Yes*	Yes	Yes
Private (<10%)	Yes	Yes**	Yes	Yes
Private (10-50%)	Yes	Yes	Yes	Yes†
Private (>50%)	Yes†	Yes**	Yes†	Yes
Institutes	Yes	Yes*	Yes*	Yes*
Medium	Yes**	Yes**	Yes**	Yes**
Large	Yes**	Yes**	Yes**	Yes**
R&D intensity	Yes**	Yes**	Yes**	Yes**
Product Innovation	Yes**	Yes*	Yes**	Yes**
Local funding	Yes*	Yes*	Yes**	Yes
EU funding	Yes	Yes	Yes†	Yes
Industries	Yes	Yes	Yes	Yes
Predicted probabilities	64.43%	64.99%	66.28%	64.86%
N	5350	5350	5350	5350
Probit model:				
Log likelihood	-3349.79	-3330.78	-3307.62	-3372.80
LR Chi2 (50)	537.31**	601.64**	800.52**	659.95**
Pseudo R^2	7.42%	8.28%	10.79%	8.91%

†$p < .10$, *$p < .05$, **$p < .01$

We perform additional robustness checks. Another specification of the dependent variable is again used. Instead of 0 and 1, we perform a factor analysis on the four objectives. We then run OLS and GLM regression on this factor. The results do not change. Furthermore, we run regressions with different specifications for our proxies for explanatory and some control variables. The results again do not change.

Discussion

In this paper, we shed new light on the relationship between search strategies of firms and their propensity to introduce environmental innovation.

Our results indicate that firms with broader horizons with respect to knowledge sources are more likely to introduce environmental innovation. Though the use of internal and market sources is the highest in driving environmental innovation, an interesting finding is how firms rely rather equally on the different sources for environmental innovation. In this manner, it is no surprise that the coefficient of breadth of knowledge type is positive and significant. This evidence of the co-occurrence of internal and external knowledge sourcing activity is consistent with previous works on the sourcing strategy for traditional innovation (Leiponen & Helfat 2010; Nelson & Winter, 1982). Firms do indeed tap into external knowledge sources in addition to internal knowledge (Arora & Gambardella, 1990). Even the largest innovation-active firms today rely on both internal sourcing and external knowledge when developing innovations (Cassiman & Veugelers, 2006). Because innovation often draws on many sources of ideas, results from knowledge recombination (Kogut & Zander, 1992; Leiponen & Helfat, 2010) and due to information asymmetry (Venkataraman, 2002), firms with access to a larger variety of sources of knowledge are in a better position to identify and develop environmental innovation opportunities. Despite discussions concerning how knowledge is tacit, the mobility of knowledge has increased tremendously over the years (Gassmann, 2006). A chance of success is indeed maximized when firms search broadly (Jewkes, Sawers, & Stillerman, 1958; Leiponen & Helfat, 2010).

An interesting finding is how firms of different sizes rely on different sources of knowledge when deciding to develop environmental innovation.

The fact that small firms draw more from internal source rather than institutional or freely-available source as we postulate may be because of resource limitations that constrain their reach out to these institutions in their search process. They might not have enough resources or time to afford to work, particularly directly, with these universities and/or research institutions. It can also be that these SMEs have more immediate concerns in dealing with short-term survival (Worthington & Patton, 2005) rather than taking a long time to conduct research with these institutions. On the other hand, it might be that these institutions are not interested in working with small firms due to the liability of smallness (Bruderl & Schussler, 1990; Freeman, Carroll & Hannan, 1983). It can be difficult for most small firms to establish appropriate network of contracts with external actors for scientific and technological expertise. After all, innovation is essentially a learning process, where it often involves more than two actors (Freel, 2003). These can be the reasons obliging small firms to look to their internally-generated knowledge as the first option.

Even though internal knowledge is the hallmark in creating firms' core competence (Gassman, 2006), research in environmental innovation is still concentrated in the public sector (Horbach et al., 2013). Moreover, the impact of university research, though substantial, is often indirect, via published works and arranged fairs or conferences (Cohen et al., 2002; Nelson, 1986). This probably explains why the marginal effects of internal, institutional and freely-available sources are rather equal.

Prior research shows that increasing firm size is positively associated with external linkages (Freel, 2003). Particularly innovative activities of larger firms are more responsive to industry innovations as compared to smaller firms (Acs et al., 1994). In line with previous research, our results show that market sources are the most important source for large firms. Although medium size firms rely on internal knowledge the most, the next most important source is market source. This can be because larger firms are more likely to both make and buy technology, as suggested by the literature. Larger firms can simply acquire new environmentally-related technologies both through the embodied format of hiring away competitors' top personnel or working with consultants, or through the disembodied format of directly acquiring other firms, buying blueprints or R&D outsourcing to other firms (Veugelers & Cassiman, 1999). Property rights theory (Grossman & Hart, 1986) and transaction costs economics (Pisano, 1990; Williamson, 1985) explain that such R&D outsourcing helps firms to tap into existing, often specialized, knowledge and aids firms in time gains, lower innovation costs, and allowing for R&D economies of scale to be more efficiently exploited (Veugelers & Cassiman, 1999).

Likewise, instead of contracts with external actors that can be expensive (Veugelers & Cassiman, 1999), another possible option is cooperative agreements (Oxley, 1997) such as alliances. In particular, environmental innovation is riskier, requires more resources than traditional innovations (Berrone et al., 2013) and is still largely unknown (Horbach et al., 2013). This option of cooperative agreement can present itself as appropriate. It allows firms to share costs and risks. It allows firms to have access to external technologies that would otherwise be impossible to get a hand on. It also allows firms to have the opportunity to exploit the synergy from knowledge complementarity among partners (Arora & Gambardella, 1990; Veugelers & Cassiman, 1999). To form or enter into such a network of alliance, it is usually based on a careful selection of partners where reputation does matter (Gulati, 1995). Additionally, hold-up problem can occur. The typical complex and uncertain nature of R&D projects can also exacerbate the problem (Veugelers & Cassiman, 1999). Thus, this could be a difficult option for smaller firms to pursue or there can be too little incentives or too high costs for smaller firms to deal with, again largely due to liability of smallness and newness (Bruderl & Schussler, 1990; Freeman et al., 1983; Stinchcombe, 1965).

Yet, firms need to maintain their internal innovative capabilities as it helps firms to secure a better bargaining position in collaborative ventures. In any case, in-house R&D activities remain important to be sought out by partners in these alliances (Gans & Stern, 1997). Consistent with previous research, our results show that this condition is particularly true if firms are large and old. Because of incumbents' threat to engage in imitative R&D increases their bargaining power during negotiations, there is a purely strategic incentive for incumbents to keep on developing their internal R&D capabilities. Incumbents indeed research more intensively than new entrants as their gains exceed that of the entrants (Gans & Stern, 1997). Moreover, firms in virtually all industries look to their own operations and external actors, particularly customers, as the predominant sources suggesting new innovations nonetheless (Cohen et al., 2002). It is no wonder that the coefficient of our internal source remains significant and positive for large firms.

Consistent with the work by Toshi et al. (2007), our study also reveals that larger firms are more likely to develop green innovations than small- and medium-sized firms. Smaller firms can have more difficulties in finding investments needed to switch to greener technologies and in dealing with complexities of environmental innovation. While previous research shows that smaller firms do recognize potential gains from green innovation, the lack of financial resources and time can constrain their ability to develop environmental innovation. For instance, the work by Worthington and Patton (2005) show that firms with fewer than 25 employees are less likely to be able to commit resources to environmental improvements. On top of that, larger firms, often publicly-held firms, are more subjected to limelight and are often more scrutinized by the public about their actions, particularly concerning social and environmental issues (McWilliams and Siegel, 2001; Waddock and Graves, 1997). The incentives for them to develop environmental innovation can also be high due to this reason.

However, careful interpretations about size are needed as we could not distinguish if these firms engage in environmental innovation for compliance purpose, operation-driven, or from a strategic stance where they see green innovation as a business opportunity to be exploited. Indeed larger firms often show that they are sincere about their environmental concerns, but they usually respond to these pressures through incremental process innovation by adopting environmental communication or management systems (Hockerts & Wustenhagen, 2010). They can be less ambitious in developing environmental innovation than smaller firms because they are already well-established and their sales have not been affected by the whole greening concept. Moreover, they are anchored by their existing assets that reflect past investments (Hockerts & Wustenhagen, 2010). Thus, though larger firms are more likely to introduce green innovation, they can just be doing simply compliance-driven green innovation type.

Limitations and future research

This study is a preliminary examination on the topic, examining the role of different search strategies in influencing environmental innovation propensity. The work presents us with numerous possibilities for future research along with theoretical and empirical refinement of environment innovations.

First, PITEC data is useful yet it has its limitations. Besides that the sample is biased, as most firms in the dataset are innovators, PITEC is also not built specifically to assess environmental innovation. It limits our approach to measuring environmental innovation from innovation objectives with environmental concerns. We cannot tell the actual outputs and/or economic values from innovation objectives. Our measure also does not allow us to distinguish between firms that introduced end-of-the pipe technology from others whose entire innovative effort is devoted toward the reduction of environmental impact. Therefore, the use of other measures of environmental innovation would help to improve this analysis. An alternative input measure can be environmental innovation expenditures. Another option can be the use of innovation effort factors combined with eco-efficiency performance parameters (Lázaro et al., 2008). The use of a different output measure, besides environmental patent, such as the number of new environmental products or processes will also offer interesting insights (Kemp & Pearson, 2007). In general, the main challenge we face is scarce information. Large-scale survey like CIS has attempted to ease the problem by including a section on innovations with environmental benefits in its 2008 questionnaire. However, the section was dropped from its later questionnaires. To date, smaller-scale specific surveys directed towards environmental innovation remain the most important method in monitoring environmental innovation despite low response rate (Kemp & Pearson, 2007).

Knowledge sourcing for environmental innovation has received the least attention in the environmental innovation surveys so far (Arundel & Kemp, 2009). A valuable value for future research could be to break down the relationship studied here into the different typologies of environmental innovation that exist. Researchers could also extend the field by analyzing the issue focusing on the recipients of the spillovers rather than just upon the source. Or researchers could combine with the data on perhaps licensing or managerial choice in shaping firms' propensity to draw from certain sources (Laursen & Salter, 2004). Beyond a diverse knowledge structure, a study of the sort of knowledge that firms possess to help enhance their absorptive capacity to introduce environmental innovation would also be interesting. Critical knowledge does not mean only technical knowledge, but it also includes awareness of where useful complementary expertise resides, be it within or outside firms (Cohen & Levinthal, 1990).

Second, PITEC data for some variables are provided in blocks of period rather than yearly, limiting us to use cross-sectional methodology. A great contribution that future research should attempt is to use panel data.

Third, PITEC provides firm level information. The absence of project level data can give rise to a bias of knowledge sourcing being jointly observed and limit conclusions we can draw about firms' sourcing strategies for environmental innovation. Results should be interpreted with care.

Fourth, theoretical and empirical analyses on determinants of environmental innovations are still rare (Horbach, 2008). A study of other determinants such as public support for environmental innovation (i.e., market-based incentives such as public financing or subsidies specifically for environmental innovations) would be fruitful. In essence, a study on any determinants of environmental innovation would help to advance the field and to help us see whether or not general innovation theories can be applied to environmental innovation contexts.

Lastly, we hope to strengthen our results by comparing our Spanish case against those of other countries that have participated in the CIS survey, as PITEC uses the same questionnaire format as CIS.

Conclusion

Existing literature has extensively addressed environmental issues and firms but innovation with respect to environment per se has not yet been analyzed in sufficient depth. A lot of understanding about environmental innovation is still needed. Our empirical results suggest that firms that rely on greater breadth of knowledge sources are more likely to introduce environmental innovation. This is no surprise in our context of environmental innovation as the extent of breadth of sources is known to be associated with new approaches towards innovation (Leiponen & Helfat, 2010). The analysis shows that firms draw from both internal and external sources (market, institutional and freely-available sources) for help with environmental innovation. Concerning external sources, information from market sources is the most important source used by firms in driving environmental innovation. Our results also indicate that larger firms are more inclined towards environmental innovation than smaller firms. The novelty of our study is that, to our knowledge, this is the first statistical study at the firm level that assesses the different types of knowledge sources together along with breadth of knowledge sources. Existing empirical studies has yet to provide hard evidence on the use of knowledge sources in relationship with environmental innovation propensity. This study hopes to provide new insights into how firms can deal with environmental innovation in this modern economy where there is a heightened demand for firms to be environmentally-friendly.

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