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Openness and environmental innovation: Does time-horizon matter?

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Abstract

The antecedents of environmental innovation and the impact of openness on technological innovation have been well studied, yet the role of external knowledge search remains largely unknown. This study explores whether six dimensions of open search (external R&D, acquisition, R&D cooperation, and three types of external information sourcing) enhance firms' environmental innovation (EI) when used either sporadically or persistently. It shows that the temporal dimension of openness matters. Persistent open knowledge search efforts are associated with a firm's propensity to introduce EI, more so than sporadic search. Furthermore, the different types of knowledge search have heterogeneous effects on different types of EI. It also shows that persistent innovation is more relevant in the case of radical EI.

Keywords: Environmental innovation; Incremental/radical; Openness; Persistence; Search.

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1. Introduction

As the 2015 worldwide climate conference in Paris established, environmental innovation has undisputed economic importance (de Marchi, 2012; Ghisetti et al., 2015; Wagner, 2007), especially as a means to reduce negative externalities associated with pollution and waste. Growing literature thus focuses on environmental innovation (EI) and its determinants, such as regulatory and institutional frameworks or supply- and demand-side factors (e.g., Cainelli et al., 2011, 2015; Del Rio Gonzalez, 2009; Horbach, 2008). To develop environmentally friendly products, firms must be able to innovate, and this ability is tightly linked to the pool of knowledge available within or accessible to an organization (e.g., Laursen and Salter, 2006; Leiponen and Helfat, 2010). Researchers thus have noted the advantages of combining internal investments with external resources (Cassiman and Veugelers, 2002), and many modern firms already have opened their innovation processes to access and exploit external knowledge while leveraging their internal resources for their core activities (Chesbrough, 2006). By increasing the openness of their innovation processes, firms may better use external knowledge and complement their internal R&D; that is, traditional R&D activities get augmented by sourcing external technologies (Chesbrough, 2006). A crucial element of open innovation activities thus involves firms' search for external knowledge (Köhler et al., 2012). Inbound search has become a salient focus of academic studies that measure how openness and external knowledge acquisition affect firms' technological innovation performance (e.g., Laursen and Salter, 2006; Leiponen and Helfat, 2010). However, investigations of external knowledge searches generally refer to technological innovation (e.g., Cassiman and Veugelers, 2002; Chatterji and Fabrizio, 2014; Hagedoorn, 1993; Laursen and Salter, 2006; Leiponen and Helfat, 2010; Zhou and Li, 2012); theory and empirical research into environmental innovations remain scarce.

A few studies posit that external knowledge search drives EI (de Marchi and Grandinetti, 2013; Triguero et al., 2013). Ghisetti et al. (2015), by assessing the relationship between the depth and breadth of knowledge sourcing and a firm's propensity to introduce EI, show that knowledge sourcing enhances various types of EI performance. They further suggest that intensive, broad interactions benefit EI, but deepening or broadening knowledge sources beyond some threshold level can be adverse. Cainelli et al. (2015) consider the specific roles of internal (internal R&D), external (alliances, networks, interorganizational relationships), and hybrid (knowledge embedded in patents, R&D services) resources. They find that external resources (present and past) are more important for EI than for other types of innovation. Although these empirical analyses strongly indicate a role of openness for EI, they do not offer a holistic view of external knowledge search that spans multiple sources. That is, Ghisetti et al. (2015) focus on external information sources, and Cainelli et al. (2015) consider R&D cooperation and acquisition. In an effort to extend extant research, we propose a more global approach, in which external knowledge search can take place not only through information sourcing but also through R&D acquisition or sharing strategies. The first contribution of our study therefore results from our focus: We do not limit our assessment to one specific external source of knowledge but instead account for different possible sources.

Moreover, acknowledging that knowledge per se is characterized by cumulativeness (Boisot, 1998), we integrate the notion of persistence in open search, such that we can track the intertemporal impact of openness on firms' EI. This intertemporal perspective has been missing from previous studies, probably due to a lack of available data (Cainelli et al., 2015). The effects of openness persistence and the conditions in which firms may benefit from such openness for EI are still unclear. The second contribution of our study therefore is our test of the effects of various, persistent sources of knowledge on different types of product EI. This analysis responds to Cainelli et al.'s (2015) call for research into whether the impacts of various resources differ across EI types. We predict that openness is a long-term process that firms can use to consolidate their competencies, such that persistent, continual open search can enhance product EI. As a third contribution, we thus distinguish incremental from radical EI to determine whether the type of openness varies with the level of novelty, in line with recent developments of the knowledge-based view (KBV; Grant, 1996) that stress knowledge as a key component of a firm's radical innovation (Zhou and Wu, 2010).

Our research question can thus be summarized as follows: What type of open knowledge search affects environmental innovation? This question comprises two sub-questions: Does persistent open knowledge search lead to more EI than sporadic search? Is persistent search more relevant for radical EI than for incremental EI? In the next section, we elaborate on our theoretical framework and propose several hypotheses. The data, drawn from the Community Innovation Survey (CIS) for 2004–2006 and 2006–2008, represent our response to Ghisetti et al.'s (2015) call to use panel data. We present the methodology and results of our econometric models, then provide some public policy recommendations, outline the limitations of this research, and suggest avenues for further research.

2. Literature review

Of the four critical success factors identified by Fleith de Medeiros et al. (2014) for environmentally sustainable product innovations (i.e., market, law, and regulation knowledge; interfunctional collaboration; innovation-oriented learning; R&D investments), we focus on external knowledge obtained from various sources through a firm's open search.

2.1. Environmental innovation and open knowledge search

External information sources are vast and varied, including customers, competitors, suppliers, and research institutions (Edquist, 1997; Lundvall, 1992). Innovative firms connect to highly diversified sets of agents through technical networks that enable them to exchange useful information (Edquist, 1997; Lundvall, 1992). When their innovation draws on many external sources of ideas and information, firms can increase their chances of success. Leiponen and Helfat (2010) demonstrate that broader innovation objectives and knowledge sources are associated with successful innovation, and successful innovators link to various information and collaboration networks. Thus, open innovation likely involves multiple external sources of information, such as clients, suppliers, consultants, government agencies, government laboratories, and university research labs. We extend existing literature pertaining to the impact of external knowledge search on technological innovation by postulating that open search also positively influences EI.

This type of innovation tends to be relatively new for firms, so they generally do not possess the internal competencies required to engage in EI (Horbach et al., 2012; Rennings and Rammer, 2009); they need external knowledge sources. Few studies offer insights into the impact of open search on EI though, so we turn to literature related to technological innovation (TI), with the assertion that environmental product innovation is a technological product innovation, with environmental benefits. The analogy between EI and TI reflects two main considerations. First, EIs tend to be particularly complex and require knowledge and competences that are unlikely to be among a firm's core competences (Horbach et al., 2012; Rennings and Rammer, 2009). That is, firms that strive for EI must go beyond their core competences (Teece et al., 1997). Second, a stylized fact emerging from scarce EI literature on sources of knowledge reveals that EIs require knowledge inputs from heterogeneous sources, possibly more so than other innovations (Ghisetti et al., 2015; Horbach et al., 2013; Rennings and Rammer, 2009). Therefore, external knowledge is an idiosyncratic EI driver.

Choosing among different sources is a crucial step in the search process, and firm managers are responsible for defining the search for external knowledge according to the sources that are available (Köhler et al., 2012). This scanning stage allows managers to decide which sources of information the firm will rely on or what type of knowledge it wants to access. It is thus crucial for the successful implementation of external knowledge sourcing (Köhler et al., 2012). To expand previous studies (e.g., Cainelli et al., 2015, on R&D cooperation and acquisition; Ghisetti et al., 2015, on information sourcing), we account for three diverse sources of external knowledge: R&D cooperation, information sourcing, and acquisition. The R&D cooperation source can increase both absorptive capacities and EI. By engaging in external relations, firms reduce the duplicated R&D efforts, risks, and costs often associated with innovation, as well as benefit from economies of scale or scope and access to technology that is not available in the market (Hagedoorn, 1993). Collaboration enhances EI by enabling economies of scale, especially for firms in the same sector (Cainelli et al., 2011) or with industrial associations, public and private entities (Del Rio Gonzalez, 2009), and environmentally concerned stakeholders (Wagner, 2007). In addition, external information sources are composed, in line with Ghisetti et al. (2015), of three sets: market (competitors, customers, suppliers), institutional (universities, governments, public research institutes), and others (journals, professional standards). These various information sources provide different resources and technological capabilities, which can complement the firm's own innovation resources and thus its innovation performance (Nieto and Santamaria, 2007).

2.2. Radical vs. incremental environmental innovation and openness

The impact of openness may differ according to the degree of innovation, which reflects the magnitude of change or degree of innovation novelty (Gatignon et al., 2002). A common distinction cites incremental versus radical innovation. An initial, radical, innovative product might launch, and then subsequent improvements occur through incremental innovations, at the product or process level, to enhance diffusion (Lhuillery, 2014). Innovations are incremental when marked by slight improvements that use existing technologies and target existing markets. Incremental EI aims at "modifying and improving existing technologies or processes to raise efficiency of resource and energy use, without fundamentally changing the underlying core technologies" (OECD, 2012, p. 3). Radical EI instead "involves a shift in the technological regime of an economy and can lead to changes in the economy's enabling technologies" (OECD, 2012, p. 4). It might include developments of breakthrough technologies or reconfigurations of product–service systems (e.g., closing the loop from resource input to waste output). It results in market or technology discontinuities, such as new technologies for existing markets or existing technologies for new markets. This type of innovation is often complex and likely to involve non-technological changes (OECD, 2012), as well as mobilize diverse actors and information sources.

Recent developments of the KBV also assert that a firm's knowledge base represents its most unique resource for radical innovation (Zhou and Li, 2012; Zhou and Wu, 2010). Because radical innovation involves a greater degree of discontinuity in the sources of innovation, previously used knowledge sources may be obsolete, so firms undertake more intensive external knowledge searches.

2.3. Environmental innovation and absorptive capacity

Openness may be essential to speed up innovative processes and improve innovation performance (Laursen and Salter, 2006), but a firm still must be endowed with an adequate absorptive capacity to use the knowledge it has acquired effectively in its innovation processes. This second face of R&D (Cohen and Levinthal, 1989) enhances the firm's ability to assimilate and exploit knowledge stemming from the external environment. We adopt Lane et al.'s (2006, p. 856) definition of absorptive capacity as a "firm's ability to utilize externally held knowledge through three sequential processes: (1) recognizing and understanding potentially valuable new knowledge outside the firm through exploratory learning, (2) assimilating valuable new knowledge through transformative learning, and (3) using the assimilated knowledge to create new knowledge and commercial outputs through exploitative learning."

Therefore, two strands of research coexist in absorptive capacity literature. Most research into the sources of radical innovation stresses the importance of external knowledge, as we have detailed, without accounting for the internal knowledge capabilities needed to develop absorptive capacities (Maes and Sels, 2014). Another stream of research adds that internal knowledge sources and internally oriented, knowledge-related capabilities can be of great importance to radical innovation. We respond to the need for more empirical research into radical innovation that combines externally and internally oriented knowledge capabilities (Maes and Sels, 2014). Specifically, we acknowledge that any type of organizational knowledge—including that originating from an external source—is created and sustained through the actions and learning of members of the organization and its absorptive capacity (Cohen and Levinthal, 1990). According to the KBV, a firm's existing knowledge base delimits its scope and capacity to comprehend and apply novel knowledge to radical innovations (Hill and Rothaermel, 2003).

Greater absorptive capacity thus fosters recognition of the value, assimilation, and application of external knowledge (Cohen and Levinthal, 1990). The ability to assimilate and exploit external knowledge is a critical component of innovative performance (Cohen and Levinthal, 1990). From this perspective, external sourcing of knowledge cannot replace in-house R&D but instead complements the internal technology base. If absorptive capacity is inadequate, knowledge sharing offers fewer direct benefits for the firm's innovation capability. Because firms need to absorb relevant knowledge from external sources, externally oriented knowledge capabilities, including absorptive capacity, become critical to innovation performance (Maes and Sels, 2014). Although some contradictory evidence exists, it involves different contexts; for example, in collaborations with competitors, the effect of absorptive capacity appears insignificant for radical innovations but strong for incremental innovations (Ritala and Hurmelinna-Laukkanen, 2013).

For EI, which are often more complex than traditional technological innovations, the second face of R&D (Cohen and Levinthal, 1989) appears more crucial for increasing the intelligibility of external knowledge, which tends to be distant from the firm's main competences (Ghisetti et al., 2015). Greater complexity also arises because non-technological elements can interfere in capacities to produce product EI. Because they involve different knowledge aspects, the need to develop an absorptive capacity for different processes, such as recognizing what is valuable, assimilating new knowledge, and using it, should be greater than that for traditional product innovations.

3. Hypothesis development

We develop three main hypotheses related to the link between persistent open search and EI (H1), the greater importance of persistent open knowledge search for radical EI than for incremental EI (H2), and the moderating role of absorptive capacity (H3). In so doing, we use Toulmin's (1969) argument model and thus present assumptions, counterarguments, and implications that allow us to elaborate each hypothesis.

Data seem to converge in suggesting that the three sources of external knowledge we investigate (R&D cooperation, information sourcing, and acquisition) benefit EI. Formal cooperation with external partners benefits EI even more than it does other types of innovations (Del Rio et al., 2013; de Marchi, 2012; Horbach, 2008). Various empirical studies testify to this positive influence: Cooperative networks with universities and public institutions drive EI (Cainelli et al., 2011; de Marchi, 2012; Triguero et al., 2013). In China, firms with more efficient, broad external networks (i.e., with suppliers, competitors, consumers, research institutes, environmental protection agencies, media, and local residents) are more engaged in EI (Cai and Zhou, 2014). With regard to the second source of external knowledge, information sourcing, Ghisetti et al. (2015) show that it enhances various types of EI performance. The third source of external knowledge, acquisition, can take two forms: acquisitions of embodied technology or acquisitions of external R&D. Some studies suggest that acquisition is important for EI (de Marchi and Grandinetti, 2013; Horbach et al., 2012, related to machinery acquisition). In their study of Spanish manufacturers, Cainelli et al. (2015) indicate that hybrid resources, such as equipment acquisitions (but not patents), are more relevant for EI than for non-EI. These results tend to suggest that the more diverse the knowledge and competences required to develop EI, the more the firm needs external resources, whether obtained by collaborating with external organizations, acquiring technology, or accessing diverse information sources.

Yet some questions remain. Horbach et al. (2013) cite the significant influence of R&D cooperation during 2006–2008 in Germany, though only for (process) innovations with environmental benefits for the firm, not for product EI (as we study here). Another study did not find any significant influence of collaboration with competitors, suppliers, or customers on EI (Cuerva et al., 2014), likely reflecting its focus on low-tech, small firms. Ghisetti et al. (2015) also suggest, for information sources, that intensive, broad interactions benefit EI, but that deepening or broadening knowledge sources beyond some threshold level can be adverse. They propose an inverted U-shaped relationship between the variety of open search and EI (Ghisetti et al., 2015), similar to indications of a curvilinear relation between wide and open search and technological innovation (Katila and Ahuja, 2002; Laursen and Salter, 2006). It is therefore not obvious that openness, as far as external knowledge search is concerned, always favors EI. For acquisition, the results are even more varied. The influence of a strategy to acquire valuable knowledge and expertise from the marketplace on EI is uncertain (Dahlander and Gann, 2010). In studies of the acquisition of patents or other external knowledge, some evidence indicates they are not significantly more important for EI than for other innovations (e.g., de Marchi, 2012; Horbach et al., 2012). Cainelli et al.'s (2015) comprehensive framework of internal, external, and hybrid resources for EI also suggests that environmental innovators possess more extensive external relationships and acquire more equipment than non-environmental innovators.

To address these counterarguments and findings, we turn to the specificity of EI, which is more complex than traditional innovation. This peculiarity means that a firm often does not have all the internal knowledge, resources, and capabilities needed to develop innovations that can reduce environmental harms. Therefore, it displays increased demand for knowledge inputs from heterogeneous sources. Collaboration modes and external knowledge sources in turn appear particularly important for EI adoption, relative to non-EI implementation, and we posit that open knowledge search benefits EI.

This prediction should be all the more true when it comes to persistent knowledge search. Research on the persistence of innovation (Clausen et al., 2012; Lhuillery, 2014) and the impacts of being a persistent innovator (Chassagnon and Haned, 2015) suggests that open search should be persistent for the firm to reap its full EI benefits. Some sources might not exert an impact at one point in time but could offer benefits when used persistently. In support of this view, Kesidou and Demirel (2012) find that recurrent investments enable important savings of energy and material. This stock must be up to date at all times and renewed constantly. With persistent open search efforts, a firm also builds skills, procedures, and routines for conducting innovation activities. Such capabilities cannot be acquired through one-shot external searches but instead develop over time, through processes of learning and shaping of routines. Knowledge building is a cumulative process (Boisot, 1998); once a specific piece of knowledge has been created, it can serve as a foundation for further developments. This cumulative quality implies that the firm's intangible assets contribute to its stock of knowledge (Boisot, 1998). Accumulating knowledge is a long-term effort, and at each point in time, the firm should be able to access and use previously created knowledge. In the KBV, the inherent cumulativeness of knowledge capital prompts persistent innovation leaders to encourage EI (Chassagnon and Haned, 2015), through market introductions of new or significantly improved goods or services that reduce environmental harms (e.g., emissions, waste, energy). In line with these arguments, we hypothesize:

Hypothesis 1: The more persistent the open knowledge search, the greater the firm's EI.

Vast research on the sources of radical innovation stresses the importance of external knowledge and provides empirical evidence of its crucial role for innovation (Maes and Sels, 2014). The limits of openness, in terms of cognitive constraints for processing knowledge inputs (Ghisetti et al., 2015), might explain why open innovation often serves to foster radical innovations. Inauen and Shenker-Wicki (2012) reveal that companies that emphasize inside-out open innovation are more likely to create radical innovations, whereas those pursuing closed innovation are more likely to exhibit better incremental innovation performance. O'Connor (2006), in a qualitative study of twelve potential innovation projects by established, large firms, concludes that radical innovation must be open. The benefits of knowledge provided by users through inventive collaborations also are greatest in new technology areas and for the generation of radical product innovations (Chatterji and Fabrizio, 2014).

Some counterarguments, contesting the greater importance of knowledge openness for radical innovations, also can be found in the literature. O'Connor (2006) indicates that for open innovation to encourage radical innovation, it needs to be managed in balance with internal capability developments. A few knowledge sources, used intensively, benefit radical innovations more than a vast breadth of sources, such that more radical innovations reduce the effectiveness of external search breadth for improving innovative performance, whereas external search depth becomes more effective (Laursen and Salter, 2006).

As a rebuttal, we argue that these empirical results relate to technological innovation, not to EI. The importance of external sources for radical innovation has not been tested in an EI context. One main argument leads us to predict that open search for external knowledge is required more for radical EI than for incremental EI though: A firm that wants to develop radical innovations, by definition, stretches the boundaries of what it knows. Due to the more complex nature of EI, relative to traditional innovation, and the increased need for external sources of knowledge for radical innovation, we take this reasoning a step further and predict that these findings hold especially for radical EI:

Hypothesis 2: Persistent open knowledge search is more relevant for radical EI than for incremental EI.

O'Connor's (2006) argument that open innovation, to be beneficial for radical innovation, needs to be balanced by internal capability developments also leads us to elaborate a third hypothesis about the moderating effect of absorptive capacity. Previous studies of EI show that absorptive capacity (usually measured by internal R&D) helps firms transform broadly sourced external knowledge into innovations (Ghisetti et al., 2015), and it is a more important driver of environmental innovators than of non-environmental innovators (Cainelli et al., 2015). Internal R&D activities raise the stock of technological knowledge in firms, by increasing their ability to capture external knowledge (Cohen and Levinthal, 1990). Corradini et al. (2014) suggest that the role of R&D for absorbing external knowledge could be reinforced, because the generated internal knowledge, as a public good, implies spillover effects from investments that aim to decrease environmental harms.

The search for knowledge from different external sources does not replace in-house innovation activities but rather complements them for EI.[2] We predict a positive moderating effect of absorptive capacity, noting that it should help firms transform external knowledge into innovative green products. This prediction is in line with Ghisetti et al.'s (2014) result that the firm's R&D increases the probability of becoming an environmental innovator and positively moderates the EI impact of the firm's knowledge sourcing.

Hypothesis 3: A firm's absorptive capacity positively moderates the impact of persistent knowledge search on EI.

4. Methodology, data and variables

4.1. Data

This study relies on firm-level data from two successive waves of the French CIS, CIS6 (conducted in 2006 for the period 2004–2006, period t – 1) and CIS8 (conducted in 2008 for the period 2006–2008, period t), provided by the French Institute of Statistics (INSEE) and collected by the Industrial Studies and Statistics Office (SESSI). The CIS follows a subject approach to innovation activities, with the firm as the statistical unit (rather than an individual innovation). It combines census and stratified sampling methods for each wave. The final data set includes only firms that responded to both waves and excludes those that entered or exited during 2004–2008. The merged sample thus has the characteristics of a balanced panel, featuring 903 manufacturing firms with at least 250 employees (see Appendix A). The information about environmental innovation is available only in CIS08, but all other data are available in both waves.

The sector composition and size distribution of the final sample did not vary substantially across periods. For the balanced data set of the CIS8, more than half of the sample (54%) consists of low or medium-low technology firms (according to the NACE[3] classifications), operating in sectors such as plastics, metals, food, textiles, and wood. The remainder of the sample (46%) features high and medium-high technology firms, operating in industries such as electronics, instruments, and chemicals.

4.2. Dependent variables

We are interested in how cumulative openness, over time, affects product innovation with environmental effects and to what extent this impact differs depending on the nature of the product innovation (radical vs. incremental). To collect information related to product

[2] However, we do not consider a synergistic relationship between internal R&D and inbound innovation but rather investigate them in the same model, systematically.

[3] NACE is the statistical classification of economic activities in the European Community, used by all member states. We classified manufacturing industries according to their global technological intensity with NACE Revision 1.1 for the t – 1 period, whereas t was covered by NACE Revision 2, according to the Eurostat classification (http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/hrst_st_esms_an9.pdf).

innovations that generate environmental benefits, we must identify firms that are product innovators and those that introduced new products with environmental effects.

Therefore, we turn to the CIS8 wave that contains information on EI. It identifies a firm as a product innovator if, in a given period of time, it introduced a new or significantly improved product, process, or organizational or marketing method. As we explain subsequently, we work only with the subsample of firms that introduced a product innovation during 2006–2008. Product innovators are defined as firms that introduced goods or services that were either new or significantly improved with respect to fundamental characteristics, technical specifications, incorporated software or other immaterial components, intended uses, or user friendliness. In this period, 42% of firms in France's manufacturing industry were product innovators. With CIS8, we also can identify firms that introduced innovations with environmental effects. An environmental innovation (EI) is a new or significantly improved product (good or service), process, organizational method, or marketing method that creates environmental benefits compared with alternatives. Firms report whether they introduced different types of EI at the production or final use stage of their products.[4]

With this information, we reconstituted a subsample of firms that introduced product innovations and also reported an environmental impact in the production or final use stage. With this definition, EI can be related to product innovation but also to organizational, process, or marketing innovations. Therefore, our estimation models include dummy variables for organizational, process, and marketing innovations.

Finally, on the basis of the subsample of firms with product innovations with environmental effects, we capture the degree of novelty by identifying products or services that are new to the market (proxy for radical innovation) and new to the firm (proxy for incremental innovation). We thus determine two dependent variables. The binary variable Radical EI equals 1 if the product innovation with environmental benefits is new to the market, and 0 otherwise. The binary variable Incremental EI is equal to 1 if the product innovation with environmental benefits is new to the firm, and 0 otherwise (see Appendixes A–C for the variable definitions, descriptive statistics, and correlation matrix). More than 75% of product innovations with environmental effects are radical, and 72% are incremental.[5] Of the firms that reported incremental EI, 65% also introduced radical EI.

4.3. Independent variables

To assess how external knowledge search affects a firm's capacity to introduce EI, we introduce the temporal dimension of openness and test whether sporadic or persistent openness (between t – 1 and t) influences EI during period t. To measure open search, we use the data in both CIS6 and CIS8 related to three sources of external knowledge: acquisition (external R&D and acquisition of technology), R&D cooperation, and sources of information. External R&D is a binary variable that measures whether firms' innovation activities are performed by other

[4] The EI at the production stage included (1) reduced material use per unit of output; (2) reduced energy use per unit of output; (3) reduced CO_2 footprint (total CO_2 production) by the enterprise; (4) replaced materials with less polluting or hazardous substitutes; (5) reduced soil, water, noise, or air pollution; and (6) recycled waste, water, or materials. The EI at the final use stage included: (7) reduced energy use; (8) reduced air, water, soil or noise pollution; and (9) improved recycling of product after use.

[5] Radical and incremental innovations are not exclusive; thus, the sum of their shares is greater than 100%. We thank an anonymous reviewer for pointing out a limitation of CIS data, namely, that companies could introduce multiple innovations over a three-year period. The CIS data do not specify which fraction of these innovations are environmental friendly. Considering the data available, we thus cannot disentangle situations marked by various types of innovation in the same reference period or obtain "pure groups" of innovators that clearly differentiate radical and incremental innovations on one hand and environmental and non-environmental innovations on the other hand.

firms or public or private research organizations and purchased by the focal firm. Acquisition is another binary variable, referring to the acquisition of advanced machinery, software, licensed patents, non-patent inventions, or know-how to produce new or significantly improved products and processes. The R&D cooperation binary variable measures whether firms cooperate with other firms or institutions to innovate. We consider three external sources of information: market sourcing, or information from suppliers, clients, competitors, consultants, commercial labs, private R&D institutes, and other firms in the sector; institutional sourcing, including those from universities, other higher education institutions, and government and public research institutes; and other sources, which include the use of patents, databases, trade literature, or fairs. These variables equal 1 if the source is crucial[6] to the firm's innovation activities and 0 otherwise.

To address the temporal dimension of openness, we measure the use of six knowledge sources during the reference period for each wave, according to the relevant binary variables for persistent external R&D (t – 1, t), persistent acquisition, persistent R&D cooperation, persistent market sourcing, persistent institutional sourcing, and persistent other sourcing. Each variable equals 1 if the firm reports continuous engagement in that strategy during both t – 1 (2004–2006) and t (2006–2008), and 0 otherwise.

The continuous variable intramural R&D intensity refers to expenditures for internal R&D during the period 2006–2008. It offers a proxy for the firm's absorptive capacity (Berchicci, 2013; Escribano et al., 2009).[7]

We also added some control variables. According to the Porter hypothesis, suitable regulation favors EI and may compensate for related costs by providing incentives for innovation, such as environmental taxes or certificates. A positive correlation arises between environmental regulation and EI (Horbach et al., 2013). Antonioli et al. (2013) find that polluting sector firms tend to innovate more environmentally than firms outside a polluting sector (Ford et al., 2014). For the current study, environmental regulation variables include existing regulations or taxes on pollution (existing regulations), as well as expected environmental financial regulations, environmental codes, and agreements for good practices within the sector (expected regulations). We add the firm's objectives for introducing EI: financial, such as benefiting from grants, subsidies, or other financial incentives (public funding); in response to legislation; for reduced labor costs (cost reduction); and due to control procedures for regularly identifying and reducing environmental impacts, such as environmental audits, environmental performance goals, or ISO 14001 certifications (control procedures). Moreover, there is a strong incentive for firms to engage in EI that are congruent with customer benefits (Kammerer, 2009). Kesidou and Demirel (2012) indicate that firms initiate EI to satisfy minimum customer and societal requirements. In line with eco-innovation literature, we also account for market-pull determinants by introducing market demand, equal to 1 if the firm introduced an EI in response to current and expected market demand from customers for environmental products or services, and 0 otherwise. Market geography accounts for market conditions, using a four-point Likert response scale (1 = local market, 2 = national, 3 = European, 4 = global market).

[6] The question asked: "How important to your enterprise's innovation activities were each of the following information sources?" The choices listed were internal, market, institutional, and other sources. Answers were ranked according to the degree of importance, from 0 ("not used") to 3 ("very crucial").

[7] The use of such variables is not optimal and constitutes a limitation (Lane et al., 2006), in view of absorptive capacity as an overarching process of multiple steps. However, as used by Cohen and Levinthal (1990) themselves, this variable is the most frequently chosen operationalization of absorptive capacity, especially in innovation surveys such as the CIS.

Finally, we add often-used control variables,[8] which may influence the firm's propensity to introduce EI. Belonging to group (which applied to 80% of the firms in our sample) is a binary variable, equal to 1 if the firm is part of a group. Firm size, measured as the natural logarithm of the number of employees, as in previous research (e.g., Cainelli et al., 2015; Cuevas-Rodríguez et al., 2014; Zhou and Li, 2012), should have a positive impact on EI, though proactive smaller firms may have profiles similar to large ones, considering that product EI can boost their competitive advantage (Klewitz and Hansen, 2014). Finally, to address the technological level of the industry, we introduce sector dummies that range from 1 to 4 to represent high-tech, medium–high-tech, medium–low-tech, and low-tech sectors, respectively.[9]

5. Main results and discussion

We test the probability of being an environmental innovator in period t as a function of present and past open search. Because EI propensities are described by binary choice equations (radical vs. incremental EI), we used a bivariate Probit model with two equations that included all explanatory variables. This approach enabled us to investigate correlations between EI categories that might be conditional on the set of explanatory variables.

5.1. Impact of sporadic vs. persistent openness

Table 1 presents the bivariate Probit estimation model for the impact of sporadic openness in t on the likelihood of EI in t. Table 2 shows the results of the estimation model in which we consider the persistent adoption of different search strategies across the lagged (t – 1) and current (t) periods.

INSERT TABLES 1 AND 2 ABOUT HERE

The results in Table 1 show that the acquisition of external knowledge or materials (Acquisition) has a significant, positive impact on incremental EI; there is no evidence for radical EI. Institutional sources appear relevant for radical EI, but we find no effect on incremental EI.[10] In Table 2, we observe that continuous market information sourcing has a significant, positive impact on radical EI, in support of the hypothesis of a crucial role of market sourcing in the search for radical product EI. The probability of introducing a radical product innovation with environmental effects also increases with the knowledge that a firm obtains through continuous exchanges with institutional actors. The parameter of persistent institutional sourcing is strongly significant and positive for radical EI. Institutional sources refer to information and knowledge stemming from public R&D establishments or universities, which often produce fundamental knowledge with a high degree of novelty. Firms that maintain persistent contacts with these institutional sources thus might enjoy important business opportunities for developing EI that are new to the market.

For incremental EI, the coefficients of persistent other knowledge sources are significant and positive. When implemented continuously in time (between t and t – 1), information stemming from conferences or professional associations appears to enhance firm capacities to introduce EI new to the firm or only imitate EI. This type of sourcing therefore serves as contact points, at which firms can find and keep in touch with potential alternatives in demand or market

8 We included all control variables in all models; for the sake of parsimony, we do not present detailed coefficients for these controls in all the tables.

[9] A table of the correlations of these variables is available on request.

[10] We also ran a model to test the impact of openness in t – 1. The lack of significant evidence suggests no effect of long-term open search strategies.

tendencies. Moreover, the results show that incremental EI is positively affected by persistent knowledge acquisition, whereas there is no such impact on radical EI.

Overall, our models provide evidence in partial support of Hypothesis 1: The more persistent the open knowledge search, the greater the firm's EI, though these results hold only for some types of EI and some types of openness. Hypothesis 2, in which we predicted that openness would be more relevant for radical than for incremental EI, instead is invalidated.[11] The different types of knowledge search that firms undertake are not homogeneous in terms of the EI they develop. Innovation with different degrees of novelty depends on different types of specific knowledge (Köhler et al., 2012).

To test Hypothesis 3, stipulating that the firm's absorptive capacity positively moderates the impact of persistent knowledge search on the firm's EI, we introduced interaction terms in the estimation models. The results for sporadic openness (Table 1) show that the coefficient of SoOther*R&D is significant and positive only for radical EI, whereas the coefficient of Other sources is not significant. Therefore, the type of sourcing is important for radical EI, but only if firms intensively invest in internal R&D. This result provides evidence of the crucial role of absorptive capacity in the relation between knowledge search and innovation. The interaction of external R&D with internal R&D intensity exerts a significant positive effect only on incremental EI, after we account for the other explanatory and control variables. Turning now to the interaction terms between persistent openness and internal R&D intensity (Table 2), we observe that the coefficient of PerSoOther*R&D is significant and positive, confirming the moderating role of internal R&D intensity in the positive relationship between persistent sourcing from scientific conferences or professional associations and the probability to introduce radical EI. The coefficient of the interaction term of persistent external R&D with intramural R&D intensity (PerExtR&D*R&D) is also significant and positive, providing strong support for the moderating role of absorptive capacity in the relationship between external R&D and radical EI. In other words, the continuous use of external R&D has beneficial impacts on radical product EI, but only for firms with absorptive capacity. The efficient exploitation of acquired technologies and knowledge demands complementary internal knowledge to lead to radical EI. These results suggest some complementarity between internal and external knowledge for radical EI, providing evidence in partial support of Hypothesis 3 for the case of persistent openness.

When it comes to incremental EI, the interaction term PerExtR&D*R&D is also significant and positive, again indicating complementarity between internal R&D and external R&D for not only radical but also incremental EI. Furthermore, the interaction term PerSoInsti*R&D is significant and positive, so information and knowledge that a firm acquires from R&D institutes or universities enhances its capacity to introduce incremental EI, though only for firms that have invested enough in intramural R&D. In other words, absorptive capacity is crucial in the relationship between institutional sourcing and incremental EI. Overall, the results provide some evidence supporting Hypothesis 3.

5.2. Impact of variety of search strategies in t

To verify the robustness of our results, we ran further regressions with different specifications of our main explanatory variable, namely, search strategy variety in t and t – 1, instead of individual sources of external knowledge. We tested whether EI depends on the variety of open search strategies, assuming that a greater number of search strategies increases the impact of openness on EI performance (see Ghisetti et al., 2015). In addition, similar to Ghisetti et al. (2015) and Laursen and Salter (2006), for the breadth of information sources, we

[11] We also ran a model to test the impact of openness in t and t – 1 on the probability to introduce EI in t. We do not find any evidence of openness in t – 1.

constructed two measures of variety, for t and t – 1 (i.e., information sources, R&D cooperation, and acquisition). The two measures are count variables, such that 0 indicates the use of no search strategy and 6 implies that all search strategies were implemented.[12]

The results for the relationship between openness diversity in t and the likelihood of EI in t appear in Table 3.[13] External search variety has a significant impact on radical EI_P and EI_U. However, the parameter for Squared Variety is positive and significant for radical EI, indicating increasing returns on openness when firms use too many search strategies. Although an openness strategy that combines various sources and the acquisition of external knowledge has not been shown to be associated with the probability of EI, broadening the search beyond a certain level is beneficial to EI. This result might reflect the cumulative process of knowledge building, in that diverse pieces of knowledge are fundamental to the development of radical EI. This result differs from previous findings of a curvilinear relationship between the variety of search strategies and the likelihood of being a technological innovator (Katila and Ahuja, 2002; Laursen and Salter, 2006) or environmental innovator (Ghisetti et al., 2015).

Table 4 contains the estimation results related to the temporal variety of search strategies in period t – 1, Variety(t – 1). All else being equal, this variable is not significant for any category of EI. This result confirms the findings for the individual search strategies and suggests no evidence of a long-term impact of search strategy investments on a firm's EI.

INSERT TABLES 3 AND 4 ABOUT HERE

6. Conclusion

This article analyzes the relevance of openness for environmental innovation. Recent empirical studies investigate the impact of external knowledge search strategies on EI (Ghisetti et al., 2015), considering different indicators of openness and ignoring the intertemporal dimension in this relation. The current study offers two new insights. First, we develop a more global approach to openness, by arguing that access to external knowledge might occur through knowledge sourcing but also with other strategies, such as R&D acquisition and cooperation. Second, we test an underlying hypothesis, namely, that a long-term process enables firms to consolidate their knowledge base, such that persistent open search strategies enhance EI. Furthermore, we estimate bivariate Probit models and undertake additional sensitivity and robustness checks, using data from two waves of the French CIS.

With these insights and approaches, our study makes three main theoretical contributions to literature on EI. First, it provides novel results related to the temporal dimension in literature on open innovation. The temporal dimension of openness matters. Persistent open search efforts are associated with a firm's propensity to introduce EI more than a sporadic openness strategy is. In particular, some openness practices are likely to propel the introduction of EI only if they are implemented continuously in time. Thus, persistent market-driven sourcing, stemming from competitors, suppliers, or consultants, is related more to the firm's capacity to introduce radical EI than are sporadic market-driven forms. In the same vein, persistent search from other sources (e.g., conferences, professional associations) seem more efficient in terms of generating incremental EI than sporadic search. To the best of our knowledge, our study thus is the first to capture the substantial time lag usually associated with

[12] Acquisition and R&D cooperation are dichotomous variables, so we cannot capture the intensity of their use or determine the depth (or intensity) of these search strategies (Ghisetti et al., 2015; Laursen and Salter, 2006).

[13] For parsimony, we do not include the coefficients of the controls and other explanatory variables, which are not our focal interest.

returns on investment of long-maturity openness strategies and their impact on EI, which need to be tracked with longitudinal data.

Second, we provide evidence of the heterogeneous impacts of different types of knowledge search on different types of EI (radical vs. incremental), thus extending Ghisetti et al.'s (2015) results. From a research perspective, openness encompasses diverse practices undertaken by firms in different, specific contexts. We consider not only information sourcing in the form of knowledge search strategies (Ghisetti et al., 2014; Köhler et al., 2012; Laursen & Salter, 2006) but also other openness practices, such as external R&D, R&D cooperation, and external knowledge acquisition. In so doing, we provide a broader perspective on the nature of search for external knowledge and its impact on the firm's capacity to introduce EI. As Köhler et al. (2012) argue, there is a pertinent issue of selectivity in firms' knowledge search. Within this study, we find heterogeneous impacts of several openness strategies on EI. Market sourcing drives radical product EI, whether firms have an absorptive capacity or not. Even without investing in absorptive capacity, firms that search for knowledge from customers, suppliers, competitors, consultants, laboratories, or private R&D institutes are more prone to develop radical product EI. This finding supports theories that suggest that radical EI entails substantial uncertainty and novelty, which may require manufacturers to interact with external partners to ensure the recyclability of their products, guarantee the supply of inputs with eco-friendly features, or keep up to date on the latest scientific developments that might benefit their EI. Moreover, the cumulative use of information from universities or R&D institutions is more likely to be associated with radical product EI; the probability of incremental EI is affected more by the cumulative use of information sources from professional associations, exhibitions, and external knowledge or material acquisition.

Third, EI are often more complex than traditional technological innovations, so the second facet of R&D, or absorptive capacity, appears particularly relevant for helping firms increase the intelligibility of external knowledge and transforming it into new clean products. To track this role, we introduced intramural R&D intensity as a proxy for absorptive capacity, with several notable results. With regard to external R&D, the persistent adoption of this strategy is associated with a heightened probability of introducing EI during the current period. Yet the strategic choice to use external R&D continuously turns out to have positive effects on both radical and incremental EI when manufacturers have undertaken internal R&D. This finding highlights a positive moderating role of absorptive capacity in the relationship between this search strategy and EI. We also observe that internal R&D intensity does not moderate the relation between market sourcing and EI. That is, complementarity between internal and external resources seemingly depends on the innovation context.

From a management perspective, this study contributes to a better understanding of the role of various open search strategies for EI and their use over time. It provides useful insights for managers who are responsible for developing these innovations. Considering the importance of firms for macroeconomic sustainable development, our research represents a step toward greater comprehension of how to use open innovation, by focusing on the external search strategies that firms should implement to develop ecologically and environmentally friendly innovations. From a public policy perspective, at least two important implications for policy makers can be derived. First, the cumulativeness of knowledge search matters. Persistent search over time is more likely to expand firms' introductions of clean products. To encourage firms to develop clean products, environmental policy should account for temporal aspects in the openness returns of environmental innovation. However, high costs due to the continual implementation of openness strategies might impede firms' incentives to continue in this direction. Thus, government policies should encourage network or cluster development, as well as propose technology or knowledge transfer structures that create stable exchange platforms among different economic authors over time. Second, a firm's internal competencies are crucial for its performance, but the leveraging role of absorptive capacity is contingent on the firm's specific characteristics and the type of EI (new to the market vs. new to the firm). Thus, though subsidies and financial incentives for clean innovation already exist, the efficiency of such policies might be improved by accounting for this contingency.

In terms of limitations, our variables are all linked to the CIS; it would be interesting to study the effect of persistent open search on persistent EI, which was not possible with our data, because the French CIS included EI only in one wave (2006–2008). Furthermore, as indicated in the methodological section, some bias may arise because the CIS data do not support separations into "pure" groups of the different types of innovations.[14] These aspects and limitations of the CIS data have been noted previously (Crépon et al., 1998; Mohnen and Röller, 2005). An interesting research perspective thus would be to apply a cluster analysis or principal component analysis to both technological and environmental innovation (radical vs. incremental) to investigate the specific links and determinants.

Moreover, prior literature has not provided a clear understanding of how open innovation approaches might work differently for EI with different motives (compliance vs. voluntary). Another relatively underdeveloped but interesting research topic pertains to the role of different governance modes for openness approaches, in relation to a firm's EI performance. Finally, analyzing complementarities among various sources of information or innovation types might reveal which combinations of external search strategies best enhance firms' pursuit of innovations that can reduce environmental harms.

[14] We thank an anonymous reviewer for highlighting this point. With our CIS data, we cannot disentangle, for example, a company with two innovations, one that was radical with no environmental impact and another that was incremental but reduced environmental impacts. If a company introduces several innovations, the CIS data cannot reveal how many of them generate environmental effects. Rather, CIS data provide general information on firms' innovation activities (e.g., innovate or not; with environmental effects or not; radical or not; incremental or not), not details about the share of each innovation that the firm has introduced.

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Appendix A. Descriptive statistics (period t: 2006–2008)

Variable	Obs	Mean	Std.	Dev.	Min
Radical EI	903	.75	.43	0	1
Incremental EI	903	.72	.42	0	1
Market sources	903	.72	.28	0	1
Institutional sources	903	.32	.46	0	1
Other sources	903	.62	.48	0	1
R&D cooperation	903	.62	.48	0	1
External R&D	903	.50	.48	0	1
Acquisition	903	.40	.49	0	1
Persistent market sourcing	903	.75	.43	0	1
Persistent institutional sourcing	903	.20	.39	0	1
Persistent other sourcing	903	.41	.49	0	1
Persistent R&D cooperation	903	.44	.49	0	1
Persistent external R&D	903	.35	.48	0	1
Persistent acquisition	903	.31	.46	0	1
Variety	903	3.29	1.25	0	6
Intramural R&D intensity	903	7.60	26.80	0	638.78
Cost reduction	903	0.56	0.49	0	1
Existing regulations	903	0.60	0.47	0	1
Expected regulations	903	0.44	0.49	0	1
Environmental codes	903	0.42	0.45	0	1
Control procedures	903	0.74	0.43	0	1
Public funding	903	0.16	0.37	0	1
Market demand	903	0.41	0.40	0	1
Size	903	5.60	1.25	5.49	9.58
Belonging to group	903	.79	.40	0	1
Market geography	903	3.68	.67	1	4
Sector dummies	903	.30	.45	0	3

Appendix B. Variable definitions

Variables	Description
Radical EI	Equal to 1 if the firm has introduced a new or significantly improved product or services with environmental benefits which are new to the market; 0 otherwise
Incremental EI	Equal to 1 if the firm has introduced a new or significantly improved product or services with environmental benefits which are new to the firm; 0 otherwise
Variety	Number of open search strategies: 6 if all strategies were adopted (acquisition, external R&D, R&D cooperation, market sourcing, institutional sourcing, other sourcing), 0 if none
Acquisition	Equal to 1 if the firm has acquired advanced machinery, equipment, computer hardware or software to produce new or significantly improved products and processes, 0 otherwise
External R&D	Equal to 1 if the firm's R&D activities are performed by other firms or public or private research organizations and then purchased by the firm, 0 otherwise
R&D Cooperation	Equal to 1 if the firm undertakes R&D cooperation for innovation activities with other firms or institutions during 2006–2008, 0 otherwise
Market sources	Equal to 1 if competitors, suppliers, customers, consultants, and private R&D institutes as sources of information are "crucial" for the firm's innovation process, 0 otherwise
Institutional sources	Equal to 1 if universities, other higher education institutions, government, or public research institutes as sources of information are "crucial" for the firm's innovation process, 0 otherwise
Other sources	Equal to 1 if conferences, scientific journals, professional associations, or technical standards as sources of information are "crucial" for the firm's innovation process, 0 otherwise
Persistent market sourcing	Equal to 1 if the firm has reported continuous market sourcing during t – 1 and t, 0 otherwise
Persistent institutional sourcing	Equal to 1 if the firm has reported continuous institutional sourcing during t – 1 and t, 0 otherwise
Persistent other sourcing	Equal to 1 if the firm has reported continuous other sourcing during t – 1 and t, 0 otherwise
Persistent cooperation	Equal to 1 if the firm has reported continuous R&D cooperation during t – 1 and t, 0 otherwise
Persistent external R&D	Equal to 1 if the firm has reported continuous external R&D during t – 1 and t, 0 otherwise
Persistent acquisition	Equal to 1 if the firm has reported continuous acquisition during t – 1 and t, 0 otherwise
Intramural R&D intensity	Ratio of intramural R&D expenditures on the number of employees during 2006-2008
Cost reduction	Equal to 1 if the firm has introduced an environmental innovation to reduce labor costs, 0 otherwise
Existing regulations	Equal to 1 if the firm has introduced an environmental innovation in response to existing environmental regulations or taxes on pollution, 0 otherwise
Expected regulations	Equal to 1 if the firm has introduced an environmental innovation in response to environmental regulations or taxes that the firm expects to be introduced in the future, 0 otherwise
Environmental codes	Equal to 1 if the firm has introduced an environmental innovation in response to voluntary codes or agreements for environmental good practices within the sector, 0 otherwise
Control procedures	Equal to 1 if the firm has procedures in place to regularly identify and reduce the environmental impacts, such as environmental audits, environmental performance goals, or ISO 14001 certification, 0 otherwise
Public funding	Equal to 1 if the firm has introduced an environmental innovation in response to the availability of government grants, subsidies, or other financial incentives, 0 otherwise
Market demand	Equal to 1 if the firm has introduced an environmental innovation in response to current and expected market demand from customers for environmental innovations, 0 otherwise
Market geography	Four-point Likert response scale: 1 = local, 2 = national, 3 = European, and 4 = global
Belonging to group	Equal to 1 if part of a group; 0 otherwise
Size	Logarithm of the number of employees
Sector dummies	High-tech manufacturing, Medium high-tech manufacturing, Medium low-tech manufacturing, Low-tech manufacturing (reference)

Appendix C. Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Radical EI (1)	1.00																	
Incremental EI (2)	0.34***	1.00																
Market sources (3)	0.06***	0.08**	1.00															
Institutional sources (4)	0.15	0.02**	0.05	1.00														
Other sources (5)	0.05**	0.12	0.27*	0.29	1.00													
R&D cooperation (6)	0.07***	0.07**	0.12	0.25	0.13	1.00												
External R&D (7)	0.09**	0.07***	0.13*	0.23**	0.07*	0.31**	1.00											
Acquisition (8)	0.01	0.13**	0.05***	0.05	0.06	0.12*	0.18**	1.00										
Persistent market sourcing (9)	0.16**	0.04*	0.56**	0.18	0.17**	0.19**	0.19***	0.01	1.00									
Persistent institutional sourcing (10)	0.12***	0.00	0.04*	0.72	0.17*	0.21	0.24**	0.03***	0.15*	1.00								
Persistent other sourcing (11)	0.05**	0.08**	0.14*	0.27***	0.65	0.18	0.16**	0.08	0.32*	0.25	1.00							
Persistent cooperation (12)	0.08	0.07***	0.12**	0.30	0.16	0.68*	0.28	0.04*	0.31***	0.36	0.28	1.00						
Persistent external R&D (13)	0.11***	0.05*	0.11*	0.28*	0.10*	0.26*	0.77	0.17**	0.27	0.37	0.24**	0.37***	1.00					
Persistent acquisition (14)	0.05*	0.08***	0.06*	0.13	0.10**	0.18**	0.23***	0.82**	0.26	0.04***	0.10*	0.18*	0.29**	1.00				
Intramural R&D intensity (15)	0.02***	- 0.02	0.00	0.08**	-0.02	0.00	0.05**	0.05**	0.08**	0.06***	0.08	0.07*	0.07	0.09	1.00			
Process innovation (16)	0.04***	0.09***	0.07*	0.09	0.10*	0.22*	0.08	0.27***	0.07*	0.08**	0.12	0.15	0.14**	0.22**	0.05	1.00		
Organizational innovation (17)	0.05***	0.11*	0.06***	0.14	0.08**	0.23*	0.12*	0.14	0.08**	0.17**	0.03**	0.14**	0.10*	0.19*	0.04*	0.28***	1.00	
Marketing innovation (18)	0.09***	0.05*	0.08***	0.08	0.09	0.12**	0.07	0.02***	0.02	0.03***	0.07**	0.12**	0.07	0.06	0.07	0.11	0.27***	1.00

Notes: *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 1. Bivariate Probit estimation results for openness in t

	Environmental innovation	
	Radical	*Incremen tal*
Openness		
Market sources (t)	0.250	0.214
	(0.207)	(0.401)
Institutional sources (t)	0.102**	0.370
	(0.232)	(0.254)
Other sources (t)	0.025	0.738
	(0.411)	(0.528)
R&D cooperation (t)	0.835	0.624
	(0.432)	(0.385)
External R&D (t)	0.254	-0.105
	(0.432)	(0.465)
Acquisition (t)	0.452	0.204***
	(0.521)	(0.368)
Moderating role of internal R&D		
SoMarket*R&D (t)	0.132	-0.025
	(0.442)	(0.014)
Soinsti*R&D (t)	0.085	-0.258
	(0.532)	(0.439)
SoOther*R&D (t)	0.642**	-0.724
	(0.552)	(0.536)
Cooperation*R&D (t)	-0.565	-0.648
	(0.432)	(0.429)
ExtR&D*R&D (t)	-0.148	0.931**
	(0.452)	(0.464)
Acquisition*R&D (t)	-0.330	-0.175
	(0.324)	(0.396)
Other explanatory variables		
Intramural R&D intensity (t)	1.141**	1.680*
	(0.232)	(0.252)
Internal sources	-0.002	0.145
	(0.021)	(0.174)
Process innovation	0.141	0.060
	(0.004)	(0.136)
Organizational innovation	-0.097	0.215**
	(0.121)	(0.119)
Marketing innovation	0.197**	0.020
	(0.110)	(0.107)
Existing regulations (t)	0.521***	1.224***
	(0.252)	(0.265)
Expected regulations (t)	0.210	0.124
	(0.280)	(0.212)
Market demand (t)	0.352**	0.021
	(0.211)	(0.225)
Environmental codes (t)	0.590***	0.874***
	(0.221)	(0.224)
Control procedures (t)	0.621***	0.445***
	(0.185)	(0.210)
Cost reduction (t)	0.565***	0.521***
	(0.101)	(0.320)
Public funding (t)	0.540*	0.102*
	(0.585)	(0.421)
Firm size	0.152	0.652
	(0.174)	(0.012)
Belonging to group	-0.166	-0.321
	(0.151)	(0.145)
Market geography	-0.085	0.152
	(0.041)	(0.085)
Sector dummies	YES	YES
Constant	1.081***	1.158***
	(0.651)	(0.542)
Observations	903	
Log Likelihood	-741.00	
p-Value	0.00	
Rho	0.792 (0.452)	
Wald χ^2	128.45	

Notes: Robust standard errors are in parentheses. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 2: Bivariate Probit estimation results for persistent openness

	Environmental innovation	
	Radical	*Incremental*
Openness		
Persistent market sourcing	0.521**	-0.528
	(0.452)	(0.352)
Persistent institutional sourcing	0.325***	-0.210
	(0.152)	(0.102)
Persistent other sourcing	0.215	0.320***
	(0.011)	(0.524)
Persistent cooperation	-1.212	0.042
	(0.521)	(0.295)
Persistent external R&D	-0.152	-0.591
	(0.520)	(0.542)
Persistent acquisition	0.101	0.391***
	(0.201)	(0.210)
Moderating role of internal R&D		
PerSoMarket*R&D	0.563	0.483
	(0.521)	(0.421)
PerSoInsti*R&D	0.452	0.221***
	(0.54)	(0.323)
PerSoOther*R&D	0.754**	-0.554
	(0125)	(0.542)
PerCooperation*R&D	0.325	0.652
	(0.665)	(0.210)
PerExtR&D*R&D	0.324*	0.052*
	(0.625)	(0.241)
PerAcquisition*R&D	0.210	0.010
	(0.352)	(0.421)
Other explanatory variables	YES	YES
Observations	903	
Log Likelihood	-725.00	
p-Value	0.00	
Rho	0.784 (0.501)	
Wald χ^2	122.65	

Notes: Robust standard errors are in parentheses. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 3: Bivariate Probit estimation results for openness variety (t)

	Environmental innovation	
	Radical	*Incremental*
Openness		
Search strategies variety (t)	-0.401	0.095
	(0.214)	(0.257)
Squared variety (t)	0.142**	-0.051
	(0.102)	(0.021)
Moderating role of internal sourcing		
Variety*R&D (t)	-0.045	0.120
	(0.142)	(0.143)
Other explanatory variables	YES	YES
Observations	903	903

Notes: Robust standard errors are in parentheses. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 4: Bivariate Probit estimation results for openness variety (t – 1)

	Environmental innovation	
	Radical	*Incremental*
Openness		
Variety (t – 1)	0.131	0.021
	(0.028)	(0.342)
Squared variety (t – 1)	0.052	0.013
	(0.027)	(0.028)
Moderating role of absorptive capacity		
Variety*R&D (t – 1)	0.010	0.015
	(0.052)	(0.041)
Other explanatory variables	YES	YES
Observations	903	903

Notes: Robust standard errors are in parentheses. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

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