Sustainability Environmental Economics and Dynamics Studies

Working Paper Series

Forms of knowledge and eco-innovation modes: Evidence from Spanish manufacturing firms

by

Alberto Marzucchi, Sandro Montresor

15/2015

SEEDS is an interuniversity research centre. It develops research and higher education projects in the fields of ecological and environmental economics, with a special focus on the role of policy and innovation. Main fields of action are environmental policy, economics of innovation, energy economics and policy, economic evaluation by stated preference techniques, waste management and policy, climate change and development.

The SEEDS Working Paper Series are indexed in RePEc and Google Scholar.
Papers can be downloaded free of charge from the following websites:
http://www.sustainability-seeds.org/.

Enquiries:info@sustainability-seeds.org

SEEDS Working Paper 15/2015
September 2015
by Alberto Marzucchi, Sandro Montresor

Forms of knowledge and eco-innovation modes: Evidence from Spanish manufacturing firms

Alberto Marzucchi[*] Sandro Montresor[†]

03 September 2015

Abstract

This paper investigates the relevance of different forms of knowledge for the firm's propensity to pursue eco-innovation (EI) strategies. The incidence of different types of internal and external knowledge is disentangled in search of specific EI-modes. We employ panel data on around 4,700 manufacturing firms from the Spanish PITEC dataset. Results show that a Science, Technology, EI-mode (STEI) prevails, though generally in an attenuated way, in the use of internal knowledge, with R&D knowledge more pivotal than some (embodied vs. disembodied) non-R&D one. On the other hand, a synthetic kind of external knowledge, typically drawn from business actors, is more important than the analytical one mainly coming from the "world of science", suggesting a Doing, Using, Interacting EI-mode (DUIEI) in external terms. Overall, a hybrid EI-mode emerges across the internal and external realm of the firm, with interesting qualifications when specific EI strategies (e.g. cleaner production technologies vs. product eco-innovations) are considered.

JEL: Q55; O31; O32.
Keywords: Eco-innovation, knowledge, innovation modes, DUI, STI.

[*] Department of International Economics, Institutions and Development - Catholic University of Milan (IT) & SEEDS, Sustainability, Ecological Economics and Dynamics Studies (IT). Email: alberto.marzucchi@unicatt.it
[†] Faculty of Economics and Law – Kore University of Enna (IT) & SEEDS, Sustainability, Ecological Economics and Dynamics Studies (IT). Email: sandro.montresor@unikore.it

1. Introduction

The socio-economic relevance of environmental innovations (hereafter EIs) is nowadays undisputed. By engaging in EIs,[3] firms can actively contribute to smart and sustainable patterns of growth (EC, 2010). Through EIs, they can actually achieve a "win-win" strategy, which combines their business objectives with the reduction of the environmental harm (Porter and van der Linde, 1995).

In light of this relevance, the drivers of EIs have recently become of paramount importance in the academic debate. Environmental regulations have initially attracted most of the attention as the key stimulus to help firms overcome the "double market-failure" – in their generation of new knowledge and in their impact on the environment – which hampers a socially efficient level of EIs. Only with a certain delay, the so-called "regulatory push/pull EI effect" of environmental policy (Rennings, 2000) has been found insufficient to account alone for the complexity and variety of EI outcomes at the firm level (Cleff and Rennings, 1999). This has stimulated a 'hybrid approach' to the analysis of EIs, in which environmental/ecological economics and innovation theory are integrated in order to retain the role of both external market conditions and internal techno-organizational capabilities along with regulatory and policy aspects.

This combined approach is currently under vibrant development and is progressively extending beyond regulations and policy actions the analysis of both EI drivers and the economic impact that EIs have with respect to "standard" innovations. For example, increasing attention has been put on demand related factors and on the technological capabilities of eco-innovative firms (e.g. Canon de Francia et al., 2007; Wagner, 2007; Horbach, 2008; Kesidou and Demirel, 2011; Horbach et al., 2012). Recently, drawing on diverse theoretical perspectives (e.g. resource-based view, dynamic capabilities, and attention theory), some focus has also been placed on the types of knowledge and resources that firms acquire/develop to become eco-innovators, with respect to "standard" innovators (e.g. De Marchi, 2012; De Marchi, and Grandinetti, 2013; Ghisetti et al., 2015; Cainelli et al., 2015). The results of these studies provide new policy implications and strategic recommendations for supporting potential eco-innovators to equip themselves with a suitable portfolio of knowledge-based assets. However, a full understanding of the impact that different forms of knowledge can have on the different EI strategies has not been reached yet. Also because of the lack of systematic empirical analyses, the extent to which the so called "knowledge-base" of firms (Malerba and Orsenigo, 1993) contributes to determining specific ways of transforming it into actual EIs, in brief, what we could call "EI-modes", is still a "black-boxed" issue, whose opening could make policy and strategic actions sharper.

In the paper we address this gap by extending to EIs a recent strand of literature, which has crystallised some distinctive modes of innovating in terms of knowledge, distinguishing between a Science, Technology, and Innovation (STI) mode – based on the production and use of codified, scientific and technical knowledge – and a Doing, Using, and Interacting (DUI) mode – based on less formalised learning processes and

[3] A standard definition of EI is provided by Kemp and Pontoglio (2007, p. 10) as "the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to [firms] and which results, through-out its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives".

on experiential know-how (Jensen et al., 2007).[4] Making an original eclectic use of this stream of literature, we argue that the location (e.g. internal or external to the firm) and the nature (e.g. R&D based or non-R&D based) of the knowledge sources of the firm affect its mode of eco-innovating, and the kind of eco-innovation it can ultimately obtain. In order to support this argument, we look for empirical evidence about the significance and relative importance that different forms of internally generated and externally acquired knowledge have for the firm's EI strategies, in general and in specific EI domains (such as, for example, in cleaner production technologies). In so doing, we address the following research questions: (i) Which kind of internal and external knowledge is more significant for the adoption of EI strategies in general? (ii) Does the relative importance of different internal and external knowledge sources point to a Science, Technology, and Eco-Innovation (STEI) rather than a Doing, Using, and Interacting Eco-Innovation mode (DUIEI)? (iii) Do different types of EI strategies rely on different types of internal and external knowledge, and thus suggest specific STEI vs. DUIEI modes?

Our empirical investigation makes use of longitudinal data coming from the Spanish Panel on Technological Innovation (PITEC). Exploiting the notable advantages that the PITEC has in terms of EI-related information, we make use of the two most recent non-overlapping waves (2012-2010 and 2009-2007) for a sample of around 4,700 manufacturing firms.

The rest of the paper is organised as follows. Section 2 illustrates the background literature. Section 3 presents the data and the econometric strategy of the empirical application. Section 4 discusses the results, and Section 5 concludes.

2. Background literature

An increasing number of studies are recognising that, far from being a quasi-automatic response to a regulatory/policy stimulus, EIs are also the outcome of the firm's ability to generate a novel product, process or organizational practice, which is marked by a favourable environmental impact. Following the resource-based view of the firm (Wernerfelt, 1984; Barney, 1991), and its recent refinements in terms of capabilities theories – in particular, with respect to the firm's absorptive capacity (Cohen and Levinthal, 1990) and dynamic capabilities (Teece et al., 1997) – EIs have been linked to specific learning processes (Zollo and Winter, 2002; Ketata et al., 2014), which firms undertake by combining the generation of internal knowledge with the absorption of external one (De Marchi, 2012; De Marchi and Grandinetti, 2013; Cainelli et al., 2015; Ghisetti et al., 2015). This view of the firm, which goes beyond the solution to information problems (e.g. contract incompleteness and information asymmetries) of the contractual perspective, and looks at knowledge as the key strategic driver of firm behaviour (Montresor, 2005), is also the grounding theoretical perspective of this paper. In particular, we refer to knowledge as the basic input that the firm is able to integrate across the organisation in order to carry out its production and innovation activities (Grant, 1996). In the case of EIs, knowledge is at the core of the firms' capacity of pursuing strategic behaviours in which they can obtain superior economic performances

[4] The STI and DUI distinction has found large application in regional and urban studies in particular (see, among the others, Asheim et al., 2012 and Asheim and Coenen, 2005).

while contributing to higher environmental performances (Porter and van der Linde, 1995a, 1995b, Ambec et al., 2013).

Following this theoretical perspective, previous work on EIs has helped to filter the validity, in the green realm, of a number of results obtained in "standard" innovation studies. Similarly, these contributions have addressed the eventual differential and/or additional relevance that "standard" innovation drivers have for eco-innovators with respect to non-eco innovators. For instance, R&D has been shown to be of greater relevance in the comparison, because of both an alleged superior novelty of EIs with respect to standard innovations (Cainelli et al., 2015) and of an entailed higher need of absorptive capacity (Ketata et al., 2014; Ghisetti et al., 2015). A similar extra-benefit for "green innovations" has been found for the firm's internal training (Cainelli et al., 2015) and investments in employees' education (Ketata et al., 2014), qualifying previous studies about the importance of human capital to become eco-innovators (Sarkis et al., 2010; Cainelli et al., 2012).

Also in terms of external knowledge, recent studies have looked for, and generally found, a different role for eco- and non-eco innovators of mechanisms like innovation cooperation (De Marchi, 2012; Cainelli et al., 2015), and the breadth and depth of external knowledge search (Ghisetti et al., 2015; Ketata et al., 2014). These results are consistent with the claim of a higher multidimensionality and systemic nature of EIs (Carrillo-Hermosilla et al. (2010).

In spite of the increasing richness of this literature, it is still rare to find a systematic analysis of the knowledge requirements entailed by EIs. Although the extant literature has stressed the importance of both internal and external knowledge sources (e.g. Ghisetti et al., 2015), no account has been explicitly given so far to whether EIs develop upon specific kinds of knowledge-base, in terms of characteristics like degrees of tacitness, complexity, independence and the like (Malerba and Orsenigo, 1993). Moreover, we do not know yet if some of these learning mechanisms – only partially considered in extant literature – matter more than others, and could thus be possibly targeted by policy and strategic actions to help their functioning.

A useful starting point to recover these aspects in the analysis of EIs can be the distinction that Jensen et al. (2007) originally made between sources of knowledge and learning mechanisms pertaining to the so-called "Science, Technology, Innovation" (STI) mode, and those referring to the "Doing, Using, Interacting Mode" (DUI). This distinction has actually stimulated a research stream that, in the field of urban and regional studies in particular (Asheim et al., 2012; Asheim and Coenen, 2005), has been used to investigate both innovative behaviours (e.g. the entrance in global vs. local innovation networks) and innovative outcomes (e.g. product vs. process, radical vs. incremental) (e.g. Herstad et al., 2014; Gonzàlez-Pernìa et al., 2015), which can be relevant also for EIs.

The STI mode refers to innovation patterns in which (business) R&D is pivotal to extend and/or develop knowledge inputs coming from the "world of science" (e.g. universities and research labs) and to apply them in better understanding how "artifacts and techniques [i.e. "technology"] employed work" (Nelson, 2004, p. 458). In terms of internal knowledge, such a mode is marked by the relevance of R&D based knowledge that, given the importance of its communication with scientists and scientific institutions (Campbell and Güttel, 2005), and that of patents as its typical outcome, is generally codified and explicit, as well as potentially global in its reach.

In external terms, the STI mode relies on the knowledge that firms can source from epistemic communities of actors (e.g. scholars and inventors) and/or institutions (e.g. universities and labs), organised around specific disciplines, through a deductive kind of learning. This is mainly, though not exclusively, an *analytical* kind of *knowledge* (Moodysson et al., 2008), which typically leads to the "know-what" and "know-why" of technology: that is, a declarative kind of knowledge (Lundvall and Johnson, 1994).

In both the previous respects, the STI mode can be expected to yield relatively more radical innovative outcomes (Jensen et al., 2007). This is an aspect that, while not among the aims of this paper, makes the present investigation particularly important also for future analyses about the critical identification of the EI radicalness (see Carrillo-Hermosilla et al., 2010).

In contrast to the STI, the DUI mode refers to innovation patterns where the "body of practice" (Nelson, 2004, pag. 458) and a "situated practical work" (Dougherty, 2004), rather than science, activate technology improvements. Innovation actually emerges from both intended (i.e. investments) and unintended (i.e. "learning-by") activities that firms carry on for their "normal" business, using the tangible (e.g. plants and machinery) and intangible (e.g. marketing and reputation) inputs for that to occur, and integrating the different organizational units through which they are managed (Jensen et al., 2007). Internally, the DUI mode thus relies on *non-R&D based knowledge*, which is typically tacit, implicit and local, but also marked by a certain variety in turn. An important part of this knowledge is actually *embodied* in the physical capital firms invest in, and whose amelioration could turn into innovation, following the seminal Salter's (1966) hypothesis. Similarly, it could be *embedded* in the human capital that firms build up with their training and education investments, still with predictable innovation outcomes (Madhavan and Grover, 1988). On the other hand, non-R&D based knowledge could also be *disembodied* (as the R&D based one is), but only indirectly related to R&D, if not even unrelated to it, and rather connected to other activities representing important "complementary assets" for innovation to take place, like the capacity of setting production facilities in place for innovative products, or shaping their design and organising their marketing to increase their economic exploitation (Rothwell, 1977; Teece, 1986).

In external terms, the DUI mode is marked by a kind of learning-by-interacting, which is typically realised through the firm's relationships with its business suppliers, customers, if not even competitors, especially in responding to the need of solving problems in the relative interaction (Lundvall, 1992). The underlying learning process usually takes place inductively and yields a *synthetic* kind of *knowledge*, amounting to the integration (i.e. "synthesis") of different pieces of existing knowledge, through their novel combination, if not even "bisociation" (Asheim and Coenen, 2005). Accordingly, it is mainly, though not exclusively, represented by a procedural kind of knowledge, leading to the "know-how" of technology (Lundvall and Johnson, 1994).

For both its internal and external specifications, the DUI mode can be expected to yield relatively more incremental innovative outcomes (Jensen et al., 2007), representing an additional aspect that could be interesting to test on EIs in future studies.

In practice, the STI and DUI modes are not so archetypically distinct, as firms usually combine the two, in particular by crossing differently their typical sources of internal and external knowledge. In this last respect, Jensen et al. (2007) actually show that "firms combining the two modes are more likely to innovate new products or services than those relying primarily on one mode or the other" (pag. 680). For this reason, rather than looking for "pure" modes of one or the other kind, research has progressively moved towards the characterisation of the actual innovation mode firms follow, using the DUI and STI modes as benchmark for such an analysis (e.g. Gonzàlez Pernìa et al., 2015).

This is also the kind of investigation we carry out in the paper. More precisely, having the STI/DUI distinction in mind, we try to identify the actual modes in which firms orient their innovative activities towards environmental objectives – in brief, their "EI-modes" – by looking at the relative importance of the different kinds of internal and external knowledge they use for doing that.

Unfortunately, in carrying out this analysis we have only limited support from the extant literature. In fact, as Horbach et al. (2013) have recognized in a recent review: "[the] issue of sources of information and knowledge used in eco-innovative activities is rarely treated in the eco-innovation literature" (p. 528). With respect to EIs in general, what we know is that they are inherently more multifaceted than their non-environmental counterparts, requiring firms to master diverse knowledge pertaining to 'design', 'users' involvement', 'product-service', and 'governance' dimensions (Carrillo-Hermosilla et al., 2010). The relative degree of novelty of EIs is also supposedly higher, as their environmental impact does pose to the firm an additional dimension along which the newness of products, processes and organisations should be pursued (Carrillo-Hermosilla et al., 2010). In fact, technologies responsible for the greening of the economy(-ies) in many cases can be considered at the early stages of their life-cycle (Consoli et al., 2015). For these reasons, in the evolutionary jargon of "technological regimes" (Winter, 1984; Breschi et al., 2000), the EI knowledge-base is in principle more "complex" (Braungart et al., 2007) and thus presumably more in need of *internal* STI-like efforts based on R&D in order to be built up.

However, the relevance of internal DUI-like activities for EIs cannot be downplayed either. Knowledge embedded in human capital, for example, has been argued to work as a fundamental competence-enhancing and motivating factor facilitating the introduction of EIs (Sarkis et al., 2010; Cainelli et al., 2012), and empirical evidence has been found of its greater relevance with respect to non-green innovators (Cainelli et al., 2015). Although more scantly, the resources and competencies acquired, in an embodied way, by investing in machinery and equipment have also been found relevant in driving EIs (Horbach et al., 2012): mainly with respect to some particular types of them, that is, end-of-pipe and integrated cleaner production technologies (Demirel and Kesidou, 2011). The evidence about the role of disembodied non-R&D knowledge is even more limited, but its importance has emerged quite neatly in some cases: like that of the knowledge connected to marketing efforts, in the case of eco-labelling for product EIs (e.g. Rennings, 2000; Pujari, 2006).

All in all, these contributions support previous research about the relevance of multiple forms of internal knowledge and resources for EIs (e.g. Cainelli et al., 2015). Accordingly, they lead us to expect that both R&D based and non-R&D based knowledge, as well as both the embodied and disembodied variants of the latter, drive the implementation of EI strategies. On the contrary, the relative importance of the different types of internal knowledge for EIs, and the EI-mode this relative importance could reveal internally, appear an open issue with respect to which our empirical application could provide important informative elements.

Coming to the role of external knowledge, this is also an emerging field of analysis, from which we can draw only limited insights. For EIs in general, what we know is that the “open innovation mode” is even more relevant than for “standard” innovations (Ghisetti et al., 2015). EIs are both systemic and multipurpose innovations, requiring the firm to combine an amount of knowledge inputs and a variety of objectives/targets (e.g. production efficiency, product quality, and environmental standards), which is disproportionate higher with respect to its internal resource endowment (Oltra and Saint Jean, 2005). The EI knowledge requirements are difficult to satisfy only internally and to find in one or a few external knowledge providers. Not surprisingly, eco-innovators have been found to “search for innovation impulses more broadly (i.e., they use more and different information sources) than other innovators” (Rennings and Rammer, 2009, p. 454), both in specific national and in international comparative contexts (Horbach et al., 2013; Cainelli et al., 2015; Ghisetti et al., 2015). In line with the results of these studies, we expect that both analytical and synthetic knowledge can play a role in driving the firms’ EI strategies.

On the other hand, both theoretical and empirical works about specific external knowledge sources/partners for EIs are sparser and again of limited use to ascertain the relative importance of STEI/DUIEI modes. In principle, knowledge sourcing from universities and research labs can be deemed decisive in providing firms with an analytical understanding of the complexity of their prospected EIs: an argument which has found general confirmation (Wagner, 2007; Triguero et al., 2013), although the relevance of analytical knowledge has appeared mainly in driving process EIs that increase, for instance, material and energy efficiency (Horbach et al., 2012). On the other hand, a number of arguments also lead us to recognise the importance of the synthetic knowledge that firms can source from the “world of business”, in particular, although not exclusively, with respect to product EIs (e.g. Triguero et al., 2013). For example, interacting with suppliers and clients provide firms with the knowledge required to deal with the needs of the upward and downward parts of the value chain of a new eco-product, like a new “green car” or an innovative “low-energy” house. Or to apply recyclability standards, or properly implement green supply chains, especially when looking for EMS certifications (e.g. EMAS) (e.g. Walker et al., 2008; Albino et al., 2009; Testa and Iraldo, 2010; Thun and Müller, 2010). More in general, the relevance of the knowledge drawn along the value-chain is supported by a specific research stream of environmental technology management (Marinova et al., 2008), which has addressed the importance of “user-producers (business) relationships” for societal innovations, and environmental innovations among them (Kivisaari et al., 2004; Rohracher, 2006; Heiskanen and Lovio, 2010). In a nutshell, EIs would represent, as societal innovations, “processes [of] co-construction of technical design and evolving social contexts, such as practices of use or changing regulatory requirements” (Rohracher, 2006, p. 17). Given this nature, the knowledge that the focal firm gets from competitors or firms operating in the same sector can be particularly relevant for its EIs. On the one hand, these business partners share the same demand characteristics and market pressures that can increase the incentive to adopt EI strategies (Horbach et al., 2012; Kesidou and Demirel, 2012). On the other hand, companies operating in the same sector are likely to be exposed to similar regulations (e.g. Marin et al., 2015), and thus likely to have implemented responsive innovative solutions (Porter and Van der Linde, 1995b) that can be applied by the focal firm too. This last set of arguments places the relevance of synthetic knowledge for EI strategies at least at the same level of that of analytical knowledge. Accordingly, it makes their relative importance, and its implications for an external STEI vs. DUIEI mode, an open issue, to which our empirical application can also contribute.

Before moving to the empirical application of the previous arguments, their reference to general EI strategies should be stressed once more. On the other hand, as different EIs appear related to different drivers (e.g. Triguero et al., 2013; Horbach et al., 2012), determining whether the balance between STEI and DUIEI is specific to the kind of EI strategies pursued by firms is extremely important too. Indeed, there are bits of evidence suggesting that the peculiarities of the EI project undertaken by a firm (e.g. product EIs vs. cleaner production technologies) could alter the picture obtainable with respect to all of its EIs in general. Accordingly, as a further element of originality with respect to the extant literature (e.g. Cainelli et al., 2015), the empirical application will integrate the general analysis with that of the specific EIs the data will allow us to capture.

3. Empirical application

Our empirical analysis is based on data stemming from the Spanish Technological Innovation Panel (PITEC), which is managed by the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT) and the Foundation for Technical Innovation (COTEC).[5]

The core sections of the PITEC are consistent with the harmonized CIS questionnaire developed by Eurostat in accordance with the Oslo Manual (OECD, 2005). In particular, since its 2004 wave, the PITEC contains firm-level information on a comprehensive panel of Spanish companies, which includes both large firms and SMEs, and both innovation-oriented and non-innovative firms. The structure of the PITEC is based on yearly waves that cover a three-year period each. In our empirical application we employ two non-overlapping waves, which cover a period extending from 2007 to 2012 (2007-2009 and 2010-2012 periods).[6] Our working sample is made of around 4,700 manufacturing firms.

The dependent variables of our analysis are built up by looking at the firm's engagement in strategies that, on the basis of an ex-post assessment (i.e. at the end of the three-year period), can be deemed eco-innovative (Cainelli et al., 2015; Antonietti and Marzucchi, 2014). In particular, we first refer to a general binary variable, *Env_Obj*, which takes on value 1 if the firm has attributed a medium or high importance to the

[5] To the best of our knowledge, ours is the EI-related study based on PITEC data, using the most recent waves of the dataset while concentrating on different EI typologies.

[6] We restrict our focus to the period 2007-2012 as prior non-overlapping PITEC waves (e.g. focusing 2006-2004) do not include the same set of questions that we exploit to create our dependent variables. Specifically, as for the environmental orientation of the firm's innovation a single question is available, which reflects whether the innovation activities have resulted in a reduced environmental impact and improvement in the health and safety conditions.

objective of reducing its environmental damage, when implementing its innovation strategy.

We also follow the extant literature and consider environmental objectives as included in the firm's overall portfolio of strategies and linked to other manufacturing technologies (Porter and van der Linde, 1995; Klassen, 2000). As a result, more specific insights are obtained by other four specific dependent variables, which combine the general environmental orientation captured by *Env_Obj* with more detailed innovation objectives. The dummies *Env_Material* and *Env_Energy* refer to EI strategies oriented towards more sustainable production technologies. The former takes on value 1, in case the firm has attributed medium or high importance *also* to the reduction of the use of materials per unit of output. Similarly, the latter is equal to 1 when the firm has *also* declared the reduction of the energy use per unit of output as medium or highly important. Hence, *Env_Material* and *Env_Energy* can be considered as capturing strategies oriented towards the adoption of cleaner production technologies (Frondel et al., 2007), which increase the material and energy efficiency of production, respectively. *Env_Other* captures EI strategies that have presumably left unaltered this material and energy efficiency of the firm's production process, and which could have had different environmental outcomes like, for instance, end-of-pipe technologies or product-like EI strategies.[7] In a residual fashion, it actually takes on value 1 for those firms having an environmental objective *not* combined with a medium or high importance in the reduction of material and energy use. Finally, *Env_Prod* attempts to capture innovation strategies mainly oriented to the introduction of eco-friendly products, resulting in the increase of the firm's green market share or in the penetration of green market niches (Ambec and Lanoie, 2008). *Env_Prod* actually takes value 1, in case the general environmental objective (of *Env_Obj*) is associated to a medium or high importance of the penetration of new markets or of the increase in the market share, and to low or nil relevance of energy and material efficiency strategies.

As far as our focal regressors are concerned, drawing on Section 2, we consider both internal and external sources of knowledge as independent variables of our environmental dependent variables.[8] As for the internal realm, we employ three continuous variables, which are created upon the information contained in the PITEC dataset about the investment in innovation activities. First of all, *R&D* captures the R&D based knowledge of the firm, and it has been created in the following three-step fashion: first, we have summed up the three-year period average expenditures in R&D (i.e. both intramural and extramural) for internal innovation; we have then divided it by the average number of employees over the same period; and we have finally applied a

[7] Due to data limitation, we are unable to single out the presence of end-of-pipe technologies. Ideally, these could have been captured by identyfing EI strategies that leave the energy and material efficiency unchanged, and are implemented as a response to environmental regulations. Unfortunately, PITEC data do not distinguish innovation objectives purely related to the compliance with environmental regulations. In fact, available data only identify in a single variable innovation objectives related to health, security and environmental regulations.

[8] It should be noted that PITEC data do not contain information on green-specific knowledge (e.g. environmental R&D or green-related information sourcing). As noted by Ghisetti et al. (2015), however, it would be misleading to separate green-oriented knowledge from non-green-oriented knowledge, in that EI requires the mastering of not only environment-specific knowledge fields but also multidisciplinary ones. In other terms, also knowledge that is not necessarily 'green', enhances the environmental performance of innovation strategies adopted and should be thus included in our analysis.

logarithmic transformation, adding one in order to avoid dropping the zeros. A second regressor, *Non-R&D_EMB*, aims at capturing the non-R&D based knowledge of embedded/embodied nature. Similarly to *R&D,* this has been created, first, by taking the three-year average of the investments firms have undertaken for the sake of innovation, both in machinery, hardware and software, and in training; we have then divided this average by the mean number of employees; and finally applied the same logarithmic transformation (adding 1).[9] Finally, *Non-R&D_DISEMB* tries to capture internal knowledge, which is still non-R&D based, but whose production and diffusion does not directly rely on embodiment mechanisms. Still referring to the same section of the questionnaire, we have referred to the firms' average expenditure in "downstream activities" related to the preparation of production and distribution activities (e.g. tests and feasibility assessments, design and setting of production facilities) and to market penetration (e.g. marketing). As before, we have divided this average by the 3-year mean number of employees and applied a logarithmic transformation to it (adding 1).

As for the knowledge sources external to the firm, we refer to the relevant PITEC section and draw on Herstad et al. (2014) in defining *Analytical* as the number of knowledge providers from which the firm has declared to acquire innovation-related information, among those in the STI realm, that is: universities, public research organizations, private research institutes and laboratories, and scientific or technical publications. Similarly, *Synthetic* is obtained by summing up the knowledge providers referable to the DUI mode, that is: suppliers, customers, competitors, industry associations, trade fairs and conferences.[10]

The remaining regressors refer to a suitable set of controls, which are included in order to minimise the potential omitted variable bias in our econometric estimations. First, we control for age and size through the two logarithmic variables *LNSize* and *LNAge*, respectively. The two dummies *Group* and *Export* instead control for the firm's belonging to a business group and exposition to international competition, respectively. We also control for additional forms of acquisition of, and exposure to, external knowledge that may affect the adoption of EI strategies, but that are conceptually distinct from our focal regressors about the nature of external knowledge, that is, *Analytical* and *Synthetic*. First, we include in our estimates *Other External*, as the log-transformed 3-year average expenditure per employee in the acquisition of external knowledge in the form of patents or licences. Rather than affecting firm's EI strategies (i.e. EI introduction), this variable is actually more a proxy for the adoption of innovations already introduced by other organizations (i.e. EI adoption/diffusion). Second, we control for whether the firm has engaged in innovation formal *Cooperation* agreements. Last, but not least, in order to avoid neglecting the fundamental role of the regulatory push/pull effect in this realm, we have to account for the fact that the

[9] While investments in machinery, on the one hand, and in training, on the other hand, would in principle require separate attention, for the sake of our EI-mode investigation, they both represent channels through which firms can get a kind of knowledge, whose embodied/embedded nature makes more related to a DUI, rather than to a STI mode.

[10] Among the list of potential external information sources, the PITEC also includes technological centres. Given that it was not possible to establish *a priori* whether to include technological centres either among the analytical or synthetic knowledge providers, we left this variables out of our baseline results. In a series of robustness checks, we included the *Tech_centre* variable (reflecting whether the firm has sourced information from technological centre) as an additional regressor. Its relation with our dependent variables is always highly insignificant. Results remain stable and are available upon request.

adoption of EI strategies may be related to regulations and policy actions. Accordingly, we first employ the dummy *Subsidy*, in order to control for the receipt of an innovation policy, although not directly related to EI requirements, because of data constraints. Furthermore, we include a set of sector dummies at the finest level of disaggregation allowed by the PITEC dataset, which should be able to account (also) for the firm's exposure to sector-specific regulations, and other sector-specific market or technological conditions that may affect the adoption of an EI strategy. Finally, we include a temporal dummy to control for macro-difference between the two waves of the PITEC data that we use.

The main descriptive statistics of the variables we have built up are reported in Table 1. Table 2 shows the correlation matrix among them. While that between *Analytical* and *Synthetic* is apparently high, VIF tests (available on request) exclude this to be a significant issue.

Insert Table 1 around here

Insert Table 2 around here

Given the nature of our dependent variables, our estimation strategy relies on a set of random-effects logit regressions, which thus account also for unobserved heterogeneity. The high persistence of the EI strategies adopted by the firms in our sample, and the consequent drop of many observations, does not make fixed-effects estimations suitable in our case. We thus estimate the following model:

$$EI_{it} = \alpha + \beta_1 R\&D_{it} + \beta_2 Non\text{-}R\&D\_EMB_{it} + \beta_3 Non\text{-}R\&D\_DISEMB_{it} + \beta_4 Analytical_{it} + \\ + \beta_5 Synthetic_{it} + \mathbf{x}'_{it}\,\gamma + \tau_t + \mu_i + \varepsilon_{it} \qquad (1)$$

where EI_{it} represents our dependent variables and $\mathbf{x}_{it}$ is the vector of our controls.

As is well known, the structure of the CIS, on which the PITEC questionnaire is based, applies a filtering to the questions asked to firms: that is, only innovative firms are required to fill the entire questionnaire. This implies the risk of a selection bias in our case, as the questions on the EI objectives of the companies are posed to innovative firms only (i.e. that have introduced either a product or process innovation, have an ongoing innovation project, or have abandoned an innovation project during the three-year period). In other terms, this implies that our dependent variables are observable for innovative firms only. We address this issue, by carrying out a robustness check based on a pooled estimation of a selection model, which accommodates the binary nature of our dependent variables: that is, a heckprobit model (with clustered standard errors).[11]

[11] To the best of our knowledge, a STATA routine that combines heckprobit in a random-effects panel data regression setting is not available yet.

In the absence of reliable exclusion restrictions available in our dataset,[12] we prefer to estimate the selection and outcome equations with the same set of covariates.[13]

4. Results

Table 3 reports the results obtained by estimating Equation 1 with a set of random-effects logit regressions. In order to address our research questions, including the analysis of the relative importance of STEI vs. DUIEI, statistical tests on the difference among the coefficients of the relevant variables have been also carried out and will be commented on in the following.

Insert Table 3 around here

Starting with the analysis of internal knowledge, with respect to general EI strategies (*Env_Obj*) (Column 1, first three rows), results show that the coefficients of *R&D*, *Non-R&D_EMB* and *Non-R&D_DISEMB* are all significant and positive. Hence, the likelihood to implement a generic EI strategy benefits from different forms of knowledge, both R&D and non-R&D based, and from the different typologies of the latter. As expected, a broad environmental target in terms of EI is associated to a wide knowledge-base, made up of a diversified portfolio of knowledge types (tacit, explicit, embodied and disembodied).

The previous interpretation is confirmed by the exceptions we find with respect to more specific EIs in Table 3 (Columns 2-5). On the one hand, R&D based knowledge still plays a role with respect to all of them, confirming the general complexity and novelty of EI strategies, already mentioned in Section 2. On the other hand, however, EI strategies directed to the introduction of cleaner production technologies, both in terms of energy (*Env_Energy*) and material (*Env_Material*) efficient processes (Columns 2 and 3), are not affected by other non-R&D knowledge but that embodied/embedded in physical and human capital (*Non-R&D_EMB*), through which these technologies are normally set in place. Conversely, EI strategies other than cleaner production technologies - aimed at adopting end-of-pipe solutions, among the others (*Env_Other*), or introducing green products (*Env_Prod*) - do not rely on other non-R&D knowledge but the disembodied one related to downstream phases of the innovation process (*Non-R&D_DISEMB*). This is consistent with the fact that end-of-pipe solutions (included in *Env_Other*) imply knowledge requirements related to setting and testing of production facilities, while green products (included in the dependent variable *Env_Other* , and more directly captured by *Env_Prod*) rely on marketing-related capabilities. In synthesis, and as expected, specific EI strategies entail more particular and dedicated

[12] As is well known, the lack of an exclusion restriction in selection models does not pose identification problems, but may only imply larger standard errors of the parameters (Wooldridge, 2001; Cameron and Trivedi, 2009).

[13] The filtering of the PITEC questions also implies that the variables on innovation-related information sourcing and cooperation is available for innovative companies only. However, *Synthetic*, *Analytical* and *Cooperation* have to be employed also in the selection equation, where observations from non-innovative companies are used too. In order to overcome this problem, we impose that the value of these variables is zero for non-innovative firms, as for non-innovative companies innovation cooperation and innovation-related information sourcing are very unlikely to be in place.

knowledge sources than general ones, enabling firms to save on those knowledge investments that are not pivotal for them. These specificities, which originally add to, and integrate, the literature on the diversity of drivers for diverse EIs (mainly, product vs. process ones up to now), should be considered by policy-makers and managers with the aim of using specific institutional and organisation leverages, respectively, in spurring the adoption of specific EI strategies.

Still focusing on internal knowledge sources, we now try to get closer to the identification of the EI-modes. More precisely, by comparing the coefficients of the relevant key variables, we now assess whether the STEI or the DUIEI mode of using internal knowledge is prevailing for implementing the EI strategies captured by our five dependent variables. First of all, pursuing a general environmental innovation objective (*Env_Obj*, in Column 1) benefits from *R&D* more than from the embodied dimension of non-R&D based knowledge (*Non-R&D_EMB*) (the difference in the coefficients is significant at the 5% level). On the contrary, the contribution of R&D is not significantly different from that of *Non-R&D_DISEMB*. At least in internal terms, therefore, it seems that generic EI strategies are adopted following a sort of “attenuated” STEI mode, where R&D is indeed the pivotal investment, but along with other less R&D-centric disembodied knowledge.

Quite interestingly, such an “attenuated” STEI mode is not restricted to general EI strategies and is rather replicated by more specific EI strategies, although with some variants. More precisely, the same general pattern as above is traceable for *Env_Other* (Column 4) and *Env_Prod* (Column 5), for which, as we said, *Non-R&D_EMB* is not significantly different from zero, and where the contribution of *R&D* is still not significantly different from that of *Non-R&D_DISEMB*. Attenuated, but in a different fashion, can also be deemed the STEI mode for EIs aimed at increasing energy efficiency (*Env_Energy*, in Column 3). While *Non-R&D_DISEMB* is not significant this time, the effect of *R&D* is not significantly different from *Non-R&D_EMB*. Once more, the centrality of R&D based knowledge is attenuated but, this time, by an embodied kind of non-R&D knowledge. A clearer STEI mode appears in place only for EIs targeting material efficiency (*Env_Material*, in Column 2): the effect of *R&D* is actually statistically greater than that of both *Non-R&D_EMB* (at the 5% level of significance) and *Non-R&D_DISEMB* (being the latter not significantly different from zero).[14] All in all, with this unique exception of a “neater” case of internal STEI mode for *Env_Material*, for which R&D is the pivotal enabler, in all the other specific EI strategies and for the general EI ones, the internal mode of eco-innovating is in fact “STEI attenuated”: it entails a pivotal role of R&D, but jointly with at least a selection of sources other than R&D, whose qualification is still EI-specific.

Coming to the external sources of knowledge (rows four and five in Table 3), both synthetic and analytical knowledge generally increase the propensity to adopt an EI strategy in general (*Env_Obj*, Column 1). This is the case also for more specific EIs that integrate a reduction in the use of materials (*Env_Material*, Column 2) and of energy (*Env_Emergy*, Column 3), which appear still in need of a wide knowledge sourcing:

[14] Although we have commented on the results reported in Table 3, which refer to the coefficients of the random effects logit regressions and the differences among them, the picture yields to unaltered evidence when we calculate the marginal effects, by imposing that the random effect (i.e. the unobserved heterogeneity component) is 0. Given the stringency of this approach, we prefer to use the marginal effects as a robustness check. Results remain available upon request.

possibly in light of the higher knowledge multidimensionality of this kind of process EIs. The only cases in which this result is not confirmed are those of the EIs that do not include cleaner production technologies aimed at increasing the efficiency of production processes (*Env_Other*, Column 4) and that mainly include product EIs (*EnvMkt_Prod*, Column 5). In these cases, the only relevant type of external knowledge is actually the synthetic one. Quite interestingly, and still consistently, a reduced orientation towards the environmental amelioration of the firm's production technologies and an increased attention towards market penetration through EIs, reduce the importance of knowledge coming from the "world of science" and increase the relevance of that stemming from the interactions with the "world of business". This is a further interesting result, which qualifies recent evidence on the relevance of the open innovation mode for EIs (Ghisetti et al., 2015).

Relating the analysis of external knowledge to that of the innovation modes, we do find that EI strategies in general benefit from synthetic knowledge more than from analytical one (Column 1), with the coefficient of *Synthetic* being significantly higher than that of *Analytical* (at the 1% level of significance). This suggests that, unlike for the internal realm, the DUIEI mode is a neater mode of eco-innovating in general. Furthermore, this is also a quite robust result across the diverse EI strategies to which we refer. Either because it is uniquely significant (as for *Env_Other* and *Env_Prod*), or because it is significantly more important than the analytical one (at the 1% level of significance, for *Env_Material* and *Env_Energy*), the synthetic knowledge that firms acquire from the external environment appears always the pivotal driver of their EI learning mechanisms. This is an original result in the exploration of the still "black-boxed" nature of the knowledge-base underlying EIs (Horbach et al., 2013). A procedural and operational kind of knowledge from the "world of business", emerging through learning-by-interacting between users and suppliers (Lundvall, 1992) or elicited from actors exposed to similar market and regulatory pressures, finds place at the side of the more investigated role of codified knowledge, such as that captured by the increasingly popular analysis of green patents (e.g. Verdolini and Galeotti, 2011; Barbieri, 2015; Dechezleprêtre et al., 2015).

Combining the results for the internal and the external realm, eco-innovators appears to follow a sort of hybrid mode all together, which combines a prevailing internal STEI with a more pivotal external DUIEI. Such a hybrid mode is actually dichotomic – i.e. more neatly STEI internally and DUIEI externally – only in the case of EI strategies directed to a higher efficiency in the use of materials (i.e. *Env_Material*). In the case of strategies that purse a reduction in the use of energy (i.e. *Env_Energy*), instead, the hybridisation is somehow unbalanced towards a general DUIEI mode, where a synthetic external knowledge is accompanied by an internal embodied (and presumably tacit and interacting-based) knowledge, though always along with R&D. In all of the other specific cases, and for EIs in general, the configuration of the hybrid EI-mode that firms follow is instead more misty. As we will say among the conclusions, these emergently heterogeneous hybrid EI-modes could have an important impact on the kind of EIs that firms can actually obtain through them, in particular in terms of radicalness.

As mentioned in Section 3, we check for the robustness of our results, by implementing a pooled heckprobit estimation, which accounts for a potential selection bias. First of all, this actually represents an issue to be considered in our analysis: the two error terms of the selection and outcome equations are actually correlated (see the Wald test in

Table 4). However, evidence emerging from Table 4 does not point to qualitatively different results (both in terms of sign and significance of the coefficients and differences between them) with respect to the random effect logit estimations.[15]

Insert Table 4 around here

Also when accounting for the selection bias, the internal prevalence of an attenuated STEI mode gets confirmed. The results obtained with the logit regressions are confirmed also externally, as the DUIEI mode still prevails.

5. Conclusions

Which are the most important drivers of eco-innovations? This question, which is attracting an increasing attention, it is still far from being a fully answered. While a first generation of studies have shown that the analysis of regulatory/legislative drivers need to be integrated with other non-institutional ones, from both the supply and the demand side (Triguero et al., 2013), a second generation of works is emerging in the attempt of identifying regularities and specifications in the functioning of the techno-economic drivers (e.g. Ketata et al., 2014; Cainelli et al., 2015; Ghisetti et al., 2015). This paper positions in this recent stream of studies and, in particular, refers to those, which have shown how EIs result from particular learning processes, drawing on specific resources and capabilities of the innovating firm (e.g. Cainelli et al., 2015; Ghisetti et al., 2015; Herstad et al., 2014). Extant studies have mainly concentrated on the identification of green-specific innovation drivers and/on the differences between eco- and non-eco innovators. In the present study we have made one step further and, looking at the whole portfolio of the firm's knowledge sources, both internal and external to its boundaries, we have investigated for the first time their relative importance in driving EI strategies. On this basis, we have tried to detect the presence of characteristic ways of eco-innovating – that is, EI-modes. We have used as a benchmark the notable distinction between a mode of innovating that mainly relies on internal formal research efforts and external sourcing of scientific/technological knowledge – the STI mode – and an innovation mode centred on non-R&D internal knowledge and external knowledge acquired from other business actors – the DUI mode. A second element of originality of the paper is represented by the search of these modes, not only with respect to the firm's propensity/capacity of eco-innovating, but also with respect to EI strategies that have specific environmental aims (e.g. energy and material efficiency, and product EI strategies). The third aspect of originality of the paper is instead more technical and represented by the use of longitudinal and updated micro-data.

The results we have obtained are quite interesting and provide novel insights about the nature of eco-innovations. First of all, the alleged superior complexity of eco-innovations (Carrillo-Hermosilla et al., 2010) makes the firms' reliance on a unique innovation mode not desirable and/or possibly not feasible. Getting across the firm's boundaries, the relative importance of the two benchmark modes we have investigated gets reversed, with the internal prevalence of a STEI mode being contrasted by that of a DUIEI externally. Overall, firms apparently need to follow a hybrid mode in eco-

[15] The only noticeable dissimilarity is the loss of significance in the difference between the coefficients of *R&D* and *Non-R&D_EMB*, for the model which employs *Env_Material* as dependent variable. This difference becomes only near-significant (p-value 0.1088).

innovating, which combines the two reference modes, and accordingly need to have multiple competencies. Metaphorically, eco-innovators are expected to be like “heroes of two worlds”, with competencies of both the “world of science (and research)” and the “world of business”.

Quite interestingly, the hybrid EI-mode that firms appear to follow takes on heterogeneous specifications across the different kind of EIs that they pursue. This is mainly due to the variety that different EI strategies reveal in terms of the most important internal knowledge sources. Indeed, a clearer-cut STEI mode emerges only with respect to EIs with the objective of reducing the use of materials per unit of output, while in the other cases the internal STEI mode is - so to say - “attenuated”, and in different ways for different EI strategies. Externally, instead, a DUIEI mode appears more pervasive, although differences in external knowledge requirements remain. These results suggest that targeting specific EI objectives mainly require to adapt the use of internal knowledge, while the firm’s interface with the outer environment can remain relatively stable. In other words, a certain flexibility in interplaying internal knowledge assets turns out to be decisive in changing EI strategies. Just to make some examples, EI strategies oriented towards cleaner production technologies are not supported by internal non-R&D based knowledge of disembodied nature. This is, on the contrary, important for product EIs or end-of-pipe solutions, where downstream phases (e.g. setting and testing production facilities and marketing) are arguably more relevant. Externally, synthetic knowledge is, as we said, prevailing. However, while for EI strategies aimed at adopting cleaner production technologies, analytical knowledge coming from the world of science is relevant too, for product EIs or end-of-pipe solutions only information from business actors really matters. In this last respect, external synthetic knowledge required for EI resembles in nature to the Von Hippel’s idea of “sticky information” (1988), characterized by the highly contextual nature of information about users’ needs and manufacturers capabilities, which makes it difficult to transfer. Accordingly, also with respect to EIs, creating stable networks of business actors can get more important than crystallising research-based relationships with universities and labs, making the synthetic/analytical balance of knowledge pending towards the former.

The results we have obtained reveal that supporting EIs is a complex task. Policy actions should go beyond the simple remediation of market-failures and, following a system approach, should also include measures that support the firm's interactions and learning. In general, policy should combine a more sustained promotion of R&D activities, with a greater support to business-to-business interactions (e.g. through inter-firm clustering and networking). However, our evidence also suggests that the set of leverages through which firms can be supported in their eco-innovative activities may be quite broad, unless a specific environmental objective could actually suggest the focus on specific kinds of sources and instruments, with a consequent saving of resources and an increase in the policy efficiency. For instance, the decision to invest in human and physical capital (e.g. through training or dedicated eco-innovation policy incentives) rather than in downstream phases really depends on the type of EI strategy pursued.

This study is of course not free from limitations and could be improved along some identified future research lines. Given their longitudinal nature and inclusion of information on EI strategies, PITEC data is an increasingly used source of information for applied analysis (Cainelli et al., 2015; De Marchi, 2012) and is emerging as an interesting alternative to the largely investigated German case (e.g. Horbach et al., 2013; 2012). However, we hope that future availability of longitudinal data will permit to extend the understanding of EI drivers beyond these two peculiar cases. Further research may also consider an aspect that was out of the scope of the present study. Hopefully, the EI-modes we have identified set the stage for the difficult evaluation of the degree of novelty and/or radicalness of EIs (see, for example, Rennings et al., 2013). Following the theoretical premises of the STI/DUI distinction we have discussed about an expected higher radicalness of the innovation outcomes of the STI mode, the hypothesis that EI strategies directed to a higher energy efficiency could yield relatively more incremental outcomes, being closer to an actual DUIEI mode overall, would be interesting to test. Similarly, it would be interesting to investigate whether a higher radicalness could be rather associated to EI strategies oriented to higher efficiency in the use of materials, being these latter characterised by the most dichotomic use of the two modes, and thus more aligned to the advantages of a combined use of the STI and DUI mode found by Jensen et al. (2007) with respect to standard innovations. In this regard, we hope that future studies, based on more refined data and methodologies to measure radicality/incrementality of EIs, will more directly consider whether STEI- rather than DUIEI-based EI strategies lead to more radical and, possibly, more remunerative EIs.

References

Albino, V., Balice, A. and Dangelico, R.M. (2009). Environmental strategies and green product development: an overview on sustainability-driven companies. *Business Strategy and the Environment*. 18 (2), 83-96.

Antonietti, R. and Marzucchi, A. (2014). Green tangible investment strategies and export performance: A firm-level investigation. *Ecological Economics*, 108, 150-161.

Asheim, B.T. and Coenen, L. (2005). Knowledge bases and regional innovation systems: comparing Nordic clusters. *Research Policy* 34, 1173–1190

Asheim, B.T., Ebersberger, B. and Herstad, S. (2012). MNCs between the global and the local: knowledge bases, proximity and distributed knowledge networks. In: Heidenreich, M. (Ed.), *Innovation and Institutional Embeddedness of Multinational Companies*. Edward Elgar, Cheltenham, pp. 77–104.

Barbieri, N. (2015). Investigating the impacts of technological position and European environmental regulation on green automotive patent activity. *Ecological Economics, 117*, 140-152

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*. 17(1), 99-120.

Berg Jensen, M., Johnson, B, Lorenz, E. and Lundvall, B.A. (2007), Forms of knowledge and modes of innovation. *Research Policy* 36 (2007) 680–693.

Braungart, M., McDonough, W. and Bollinger, A. (2007). A cradle-to-cradle design, creating healthy emissions: a strategy for eco-effective product and system design. *Journal of Cleaner Production* 15 (13–14), 1337–1348.

Breschi, S., Malerba, F. and Orsenigo, L. (2000). Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal*, 110(463), 388–410

Cainelli, G., De Marchi, V. and Grandinetti, R. (2015), Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms. *Journal of Cleaner Production* 94 (2015) 211-220.

Cainelli, G., Mazzanti, M. and Montresor, S. (2012). Environmental innovations, local networks and internationalization. *Industry and Innovation*. 9 (8), 697-734.

Cameron, A.C. and Trivedi, P.K.(2009). Microeconometrics using Stata. Stata Press, College Station, Texas, USA.

Campbell, DFJ, and Güttel, WH (2005). Knowledge production of firms: research networks and the―scientification of business R&D. *International Journal of Technology Management*, 31(1/2), 152–175.

Cañón-de-Francia, J., Garcés-Ayerbe, C., and Ramírez-Alesón, M. (2007). Are more innovative firms less vulnerable to new environmental regulation?.*Environmental and Resource Economics*, *36*(3), 295-311.

Carrillo-Hermosilla, J., del Río, P. and Konnola, T. (2010). Diversity of eco-innovations: reflections from selected case studies. *Journal of Cleaner Production*. 18 (10/11), 1073-1081.

Chesbrough, H. (2003) *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business Press, USA

Chesbrough, H. and Vanhaverbeke, W., West, J. (2006). *Open Innovation: Researching a New Paradigm*. Oxford University Press, USA.

Cleff, T. and Rennings, K. (1999). Determinants of environmental product and process innovation. *European Environment* 9 (5), 191–201.

Cohen, W.M. and Levinthal, D.A. (1990). Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35 (1), 128-152.
Consoli, D., Marin, G., Marzucchi, A., and Vona, F. (2015). Do green jobs differ from non-green jobs in terms of skills and human capital? SPRU Working Paper Series 2015/16
Cuerva, M.C., Triguero-Cano, A. and Corcoles, D. (2014). Drivers of green and non-green innovation: empirical evidence in low-tech SMEs. *Journal of Cleaner Production*. 68 (1), 104-113.
De Marchi, V., 2012. Environmental innovation and R&D cooperation: empirical evidence from Spanish manufacturing firms. *Research Policy* 41 (3), 614-623.
De Marchi, V. and Grandinetti, R. (2013). Knowledge strategies for environmental innovations: the case of Italian manufacturing firms. *Journal of Knowledge Management*. 17 (4), 569e582.
Dechezleprêtre, A., Neumayer, E., and Perkins, R. (2015). Environmental regulation and the cross-border diffusion of new technology: Evidence from automobile patents. *Research Policy*, *44*(1), 244-257.
Del Río, P., Penasco, C. and Romero-Jordan, D. (2013). Distinctive features of environmental innovators: an econometric analysis. *Business Strategy and the Environment*. http://dx.doi.org/10.1002/bse.1822.
Demirel, P. and Kesidou, E. (2011). Stimulating different types of eco-innovation in the UK: government policies and firm motivations. *Ecological Economics*. 70 (8), 1546-1557.
Dougherty, D. (2004). Organizing practices in services: capturing practice-based knowledge for innovation. *Strategic Organization* 2, 35–64.
European Commission (EC) (2010). Communication from the Commission, Europe 2020. A strategy for smart, sustainable and inclusive growth. Brussels, 3.3.2010.
Frondel, M., Horbach, J., and Rennings, K. (2007). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. *Business Strategy and the Environment*, *16*(8), 571-584.
Ghisetti, C., Marzucchi, A. and Montresor, S. (2015). “The open eco-innovation mode. An empirical investigation of eleven European countries”, *Research Policy* 44 (2015) 1080–1093.
Gonzalez-Pernıa, J.L., Parrilli, M.D. and Pena-Legazkue, I. (2015). STI–DUI learning modes, firm–university collaboration and innovation. *Journal of Technology Transfer* 40:475–492.
Grant. R. (1996), Toward a knowledge-based theory of the firm, *Strategic Management Journal*, 17(S2), 109–122.
Heiskanen, E. and Lovio, R. (2010), *User−Producer Interaction in Housing Energy Innovations Energy Innovation as a Communication Challenge*, 14(1), 91-102.
Herstad, S.J., Wiig Aslesen, H. and Ebersberger, B. (2014), On industrial knowledge bases, commercial opportunities and global innovation network linkages. *Research Policy* 43 (2014) 495– 504.
Horbach, J. (2008). Determinants of environmental innovation—new evidence from German panel data sources. *Research policy*, *37*(1), 163-173.
Horbach, J., 2008. Determinants of environmental innovation: new evidence from German panel data sources. *Research Policy* 37 (1), 163e173.

Horbach, J., Oltra, V. and Belin, J., 2013. Determinants and specificities of eco-innovations. An econometric analysis for the French and German Industry based on the Community Innovation Survey. *Industry and Innovation* 20 (6), 523–543.

Horbach, J., Rammer, C., and Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull. *Ecological Economics*, *78*, 112-122.

Horbach, J., Rammer, C. and Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact – the role of regulatory push/pull. Technology push and market pull. *Ecological Economics* 78, 112–122.

Kemp, R. and Pontoglio, S. (2007). Workshop Conclusions on Typology and Frame-work. Measuring Eco-innovation (MEI) Project. UNU MERIT, Maastricht, Available from: http://www.oecd.org/greengrowth/consumption-innovation/43960830.pdf

Kesidou, E., and Demirel, P. (2012). On the drivers of eco-innovations: Empirical evidence from the UK. *Research Policy*, *41*(5), 862-870.

Ketata, I, Sofka, W., and Grimpe, C. (2014), The role of internal capabilities and firms' environment for sustainable innovation: evidence for Germany. *R&D Management* 45, 1, 61-75.

Kivisaari S., R. Lovio, and E. Vayrynen. 2004. Managing experiments for transition. In *System innovation and the transition to sustainability: Theory, evidence and policy*, edited by B. Elzen et al. Cheltenham, UK: Edward Elgar.

Klassen, R. D. (2000). Exploring the linkage between investment in manufacturing and environmental technologies. *International Journal of Operations & Production Management*, 20(2), 127-147

Lundvall, B.-A° . (Ed.), 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. Pinter Publishers, London.

Lundvall, B.-A° . and Johnson, B. (1994). The learning economy. *Journal of Industry Studies* 1, 23–42.

Madhavan, R. and Grover, R. (1998). From Embedded Knowledge to Embodied Knowledge: New Product Development as Knowledge Management. *Journal of Marketing*. Vol. 62, No. 4, pp. 1-12.

Malerba, F. and Orsenigo, L. (1993), Technological regimes and firm bebavior, *Industrial and Corporate Change*, 2(1), 45-71.

Marin, G., Marzucchi, A., and Zoboli, R. (2015). SMEs and barriers to Eco-innovation in the EU: exploring different firm profiles. *Journal of Evolutionary Economics*, 25(3), 671-705

Marinova, D., Annandale, D. and Phillimore, J. (2008), *The International Handbook on Environmental Technology Management*. London, Edward Elgar.

Moodysson, J., Coenen, L. and Asheim, B. (2008). Explaining spatial patterns of innovation: analytical and synthetic modes of knowledge creation in the Medicon valley life science cluster. *Environment and Planning A* 40,1040–1056.

Montresor S. (2004). Resources, capabilities, competences and the theory of the firm, *Journal of Economic Studies*, 31(5), 409 – 434.

Nelson, R.R. (2004). The market economy and the scientific commons. *Research Policy* 33, 455–471.

OECD/Eurostat (2005), Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data, 3rd Edition, The Measurement of Scientific and Technological Activities, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264013100-en

Oltra, V. and Saint Jean, M. (2005). Environmental innovation and clean technology: an evolutionary framework. *International Journal of Sustainable Development* 8(3), 153–172.

Porter, M.E., and van der Linde, C., (1995a). Green and competitive: ending the stalemate. *Harvard Business Review*. 73 (5), 120-134.

Porter, M.E. and van der Linde, C. (1995b). Toward a new conception of the environment competitiveness relationship. *Journal of Economic Perspective*. 9 (4), 97e118.

Pujari, D. (2006). Eco-innovation and new product development: understanding the influences on market performance. *Technovation* 26 (1), 76–85.

Rennings, K. (2000). Redefining innovation: eco-innovation research and the contribution from ecological economics. *Ecological Economics*. 32 (2), 319-332.

Rennings, K. and Rammer, C. (2009). Increasing Energy and resource efficiency through innovation – an explorative analysis using innovation survey data. *Czech Journal of Economics and Finance* 59 (1), 442–459.

Rennings, K., P. Markewitz, and S. Vogele (2013). How clean is clean? incremental versus radical technological change in coal-fired power plants. *Journal of Evolutionary Economics* 23 (2), 331–355.

Rohracher (2006). Users as a source of learning in environmental technology management. In Marinova, D., Annandale, D., Phillimore, J. (eds), *The International Handbook on Environmental Technology Management*, London, Edward Elgar.

Rothwell, R. (1977). The characteristics of successful innovators and technically progressive firms. *R&D Management* 7, 191–206.

Salter, W.E.G. (1960). *Productivity and Technical Change*. Cambridge University Press, Cambridge.

Sarkis, J., Gonzalez-Torre, P. and Adenso-Diaz, B. (2010). Stakeholder pressure and the adoption of environmental practices: the mediating effect of training. *Journal of Operations Management*. 28 (2), 163-176.

Teece, D.J. (1986), Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, 15(6), 285–305.

Teece, D.J., Pisano, G., and Shuen, A., (1997). Dynamic Capabilities and Strategic Management. *Strategic Management Journal*, Vol. 18, No. 7. 509-533.

Testa, F., and Iraldo, F. (2010). Shadows and lights of GSCM (Green Supply Chain Management): determinants and effects of these practices based on a multi-national study. *Journal of Cleaner Production*, *18*(10), 953-962.

Thun, J.-H. and Müller, A., 2010. An empirical analysis of green supply chain management in the German automotive industry. *Business Strategy and the Environment*. 19 (2), 119-132.

Triguero, A., Moreno-Mondéjar and L., Davia, M.A. (2013), Drivers of different types of eco-innovation in European SMEs. *Ecological Economics* 92 (2013) 25–33.

Verdolini, E., and Galeotti, M. (2011). At home and abroad: An empirical analysis of innovation and diffusion in energy technologies. *Journal of Environmental Economics and Management*, *61*(2), 119-134.

Von Hippel, E. 1998. Economics of product development by users: The impact of “sticky” local information. *Management Science* 44(5): 629– 644.

Wagner, M. (2007). On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. *Research Policy*, *36*(10), 1587-1602.

Walker, H., Di Sisto, L., and McBain, D. (2008). Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors. *Journal of Purchasing and Supply management*, *14*(1), 69-85.

Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal*. 5 (2), 171-180.

Winter, Sidney G. (1984). Schumpeterian competition in alternative technological regimes, *Journal of Economic Behavior & Organization*, 5(3), 287-320.

Wooldridge, J.M. (2001) Econometric Analysis of Cross Section and Panel Data. MIT Press, Cambridge, USA

Zollo, M. and Winter, S. (2002). Deliberate Learning and the Evolution of Dynamic Capabilities. Organization Science. 13(3), 339 – 351.

Table 1 – Descriptive statistics

Variable	Mean	N	SD	p25	p50	p75	Min	Max
Env_Obj	0.532	7858	0.499	0	1	1	0	1
Env_Material	0.349	7858	0.477	0	0	1	0	1
Env_Energy	0.364	7858	0.481	0	0	1	0	1
Env_Other	0.168	7858	0.374	0	0	0	0	1
Env_Prod	0.144	7858	0.352	0	0	0	0	1
R&D*	5555.734	7858	12715.529	526.98	2199.243	5839.096	0	3.62E+05
Non-R&D_EMB*	879.971	7858	3752.012	0	24.841	425.08	0	98783.922
Non-R&D_DISEMB*	563.855	7858	5195.068	0	49.803	312.336	0	2.94E+05
Synthetic	3.117	7858	1.648	2	4	4	0	5
Analytical	2.067	7858	1.565	1	2	4	0	4
LnSize	4.215	7858	1.303	3.271	4.105	5.116	0.693	9.194
LnAge	3.27	7858	0.597	2.89	3.296	3.689	0	5.182
Group	0.442	7858	0.497	0	0	1	0	1
Subsidy	0.374	7858	0.484	0	0	1	0	1
Cooperation	0.35	7858	0.477	0	0	1	0	1
Export	0.861	7858	0.346	1	1	1	0	1
Other External	50.723	7858	833.141	0	0	0	0	54570.254

*Values before log transformation

Table 2 – Correlation matrix

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Env_Obj (1)	1																
Env_Material (2)	0.6867	1															
Env_Energy (3)	0.709	0.8076	1														
Env_Other (4)	0.4221	-0.1225	-0.3401	1													
Env_Prod (5)	0.3854	-0.1026	-0.3106	0.9132	1												
R&D* (6)	0.2075	0.1605	0.1507	0.0829	0.1066	1											
Non-R&D_EMB* (7)	0.0839	0.0766	0.0853	0.0023	0.0047	-0.0306	1										
Non-R&D_DISEMB* (8)	0.1303	0.0976	0.0947	0.052	0.0817	0.2311	0.218	1									
Synthetic (9)	0.3961	0.3413	0.3389	0.0926	0.1098	0.3273	0.0791	0.2099	1								
Analytical (10)	0.3756	0.3242	0.3271	0.0804	0.0894	0.341	0.0697	0.1599	0.6959	1							
LnSize (11)	0.1712	0.1912	0.2042	-0.0342	-0.0201	0.0035	0.0529	0.0084	0.1297	0.1963	1						
LnAge (12)	0.0678	0.0484	0.0692	0.0015	0.0033	-0.0087	-0.0111	0.0024	0.0379	0.067	0.3208	1					
Group (13)	0.1171	0.1332	0.1401	-0.0239	-0.01	0.0793	0.0341	0.0098	0.0758	0.1446	0.5402	0.0787	1				
Subsidy (14)	0.1614	0.1285	0.1251	0.0544	0.0701	0.3286	0.1058	0.1503	0.2181	0.3032	0.1584	0.0333	0.1139	1			
Cooperation (15)	0.1922	0.1619	0.1714	0.036	0.0473	0.2515	0.1016	0.1358	0.2441	0.353	0.1912	0.0536	0.1922	0.3521	1		
Export (16)	0.0807	0.0677	0.0686	0.0194	0.0373	0.1464	0.0176	0.0848	0.1193	0.1276	0.2115	0.1405	0.1277	0.1194	0.0974	1	
Other External (17)	0.0408	0.04	0.042	0.0004	0.0097	0.0263	0.1293	0.1331	0.0545	0.0676	0.0881	0.0329	0.0584	0.0844	0.0898	0.046	1

Table 3 – Random effects Logit estimations

	(1) Env_Obj	(2) Env_Material	(3) Env_Energy	(4) Env_Other	(5) Env_Prod
R&D	0.0847***	0.0876***	0.0612***	0.0534***	0.0895***
	0.0162	0.0183	0.0178	0.0185	0.0216
Non-R&D_EMB	0.0385***	0.0400***	0.0494***	-0.009	-0.0141
	0.013	0.0138	0.0136	0.0137	0.015
Non-R&D_DISEMB	0.0531***	0.0221	0.0207	0.0362**	0.0691***
	0.0142	0.0154	0.015	0.0154	0.0169
Synthetic Knowledge	0.5964***	0.6123***	0.5933***	0.1766***	0.2389***
	0.0413	0.0467	0.0448	0.0401	0.0446
Analytical Knowledge	0.2641***	0.2617***	0.2624***	0.0229	-0.0126
	0.0405	0.0423	0.0419	0.0441	0.0478
Year_2012	0.0096	0.0764	0.1132	-0.1386*	-0.1216
	0.0699	0.0719	0.0711	0.0773	0.0835
LNSize	0.2533***	0.3403***	0.3617***	-0.1415***	-0.1087**
	0.0464	0.05	0.0491	0.0489	0.0533
LNage	0.0891	-0.0622	0.0364	0.077	0.0568
	0.0812	0.0865	0.0843	0.0848	0.0918
Group	0.0554	0.1845	0.1737	-0.1399	-0.0893
	0.1061	0.1135	0.1113	0.1142	0.1255
Subsidy	0.2124**	-0.017	0.0115	0.2383**	0.2824***
	0.0958	0.1009	0.0982	0.1002	0.1075
Other External	-0.007	0.0041	0.0017	-0.0129	0.003
	0.0347	0.0361	0.0355	0.0386	0.0412
Cooperation	0.3385***	0.2443**	0.2857***	0.0312	0.0513
	0.0988	0.1015	0.0995	0.1036	0.1115
Export	-0.0732	-0.0851	-0.1154	0.109	0.2332
	0.1279	0.1417	0.1409	0.1377	0.1545
_cons	-5.4722***	-6.8165***	-6.7666***	-3.4243***	-4.9096***
	0.4717	0.5501	0.533	0.5017	0.588
lnsig2u	1.3452***	1.4808***	1.4504***	1.1154***	1.2625***
	0.1028	0.0993	0.0993	0.1199	0.1231
sigma_u	1.9593***	2.0968***	2.0651***	1.7466***	1.8799***
	0.1007314	0.1041539	0.1025727	0.1046976	0.1157002
N	7858	7858	7858	7858	7853
Log pseudolikelihood	-4314.9212	-4142.1649	-4199.1487	-3353.7011	-3004.9524
Wald chi2(36)	707.01 ***	602.91 ***	609.83 ***	152.49***	178.56***

Coeff/Robust standard errors (clustered by ID). ***. **. * denote 1%. 5% and 10% levels of significance. respectively. Sector dummies included

Table 4 – Pooled heckprobit estimations

	(1) Env_Obj	(2) Env_Material	(3) Env_Energy	(4) Env_Other	(5) Env_Prod
Outcome Equation					
R&D	0.0294***	0.0296***	0.0220***	0.0140*	0.0277***
	0.0065	0.007	0.0069	0.0075	0.0083
Non-R&D_EMB	0.0154***	0.0163***	0.0202***	-0.0074	-0.0081
	0.0052	0.0053	0.0053	0.0056	0.0059
Non-R&D_DISEMB	0.0159***	0.0055	0.0052	0.0116*	0.0247***
	0.0056	0.0059	0.0058	0.0063	0.0066
Synthetic Knowledge	0.1983***	0.2076***	0.2008***	0.0336**	0.0616***
	0.015	0.0167	0.0164	0.0166	0.0177
Analytical Knowledge	0.1153***	0.1021***	0.1041***	0.0151	0.0024
	0.0156	0.0158	0.0158	0.0178	0.0187
Year_2012	0.0262	0.0494*	0.0595**	-0.0410	-0.0326
	0.0269	0.0267	0.0267	0.0311	0.0322
LNSize	0.0972***	0.1301***	0.1377***	-0.0594***	-0.0448**
	0.0177	0.0183	0.018	0.0195	0.0204
LNage	0.0303	-0.0265	0.0111	0.0263	0.0166
	0.0314	0.0321	0.0316	0.0343	0.0355
Group	0.0169	0.0614	0.0636	-0.0563	-0.0378
	0.0411	0.0425	0.0421	0.0458	0.0484
Subsidy	0.0525	-0.0088	-0.0212	0.0915**	0.1111***
	0.0376	0.0385	0.0379	0.041	0.0424
Other External	-0.0037	0.0005	0.0012	-0.0065	-0.0001
	0.0134	0.0139	0.0136	0.0157	0.0161
Cooperation	0.1024***	0.0613	0.0893**	-0.0009	0.0053
	0.0386	0.0387	0.0384	0.0423	0.0441
Export	-0.0484	-0.0628	-0.0734	0.0452	0.0994*
	0.0507	0.0543	0.0538	0.056	0.0598
_cons	-1.9218***	-2.4248***	-2.4192***	-1.1259***	-1.6656***
	0.172	0.1905	0.1869	0.1988	0.2229
Selection Equation					
R&D	0.2206***	0.2232***	0.2205***	0.2228***	0.2232***
	0.0121	0.0122	0.0122	0.0121	0.0122
Non-R&D_EMB	0.2716***	0.2790***	0.2776***	0.2698***	0.2740***
	0.0201	0.0203	0.0202	0.0197	0.02
Non-R&D_DISEMB	0.2068***	0.2072***	0.2084***	0.2083***	0.2080***
	0.024	0.0243	0.0242	0.024	0.0243
Synthetic Knowledge	6.8664***	6.8666***	6.8665***	6.8664***	6.8664***
	0.1967	0.2488	0.2344	0.1214	0.1403
Analytical Knowledge	5.7470***	5.7470***	5.7470***	5.7470***	5.7470***
	0.167	0.1986	0.1975	0.1708	0.1858
Year_2012	-0.7956***	-0.8018***	-0.8042***	-0.7934***	-0.8028***
	0.0677	0.0684	0.068	0.0683	0.0688
LNSize	0.1655***	0.1699***	0.1713***	0.1719***	0.1740***
	0.03	0.0301	0.0304	0.0298	0.0301
LNage	0.0717	0.0681	0.0761	0.0670	0.0688
	0.0617	0.062	0.0623	0.0616	0.0621
Group	0.0238	0.0252	0.0331	0.0141	0.0134
	0.0807	0.0815	0.0812	0.0809	0.0816
Subsidy	0.7697***	0.7820***	0.8106***	0.7455***	0.7602***
	0.1967	0.1923	0.201	0.1884	0.1927
Other External	0.0759	0.0791	0.0805	0.0763	0.0799
	0.0944	0.0962	0.0956	0.0951	0.0969
Cooperation	7.0351***	7.0350***	7.0350***	7.0351***	7.0350***
	0.2055	0.2557	0.249	0.2075	0.2204
Export	0.1674**	0.1762**	0.1664**	0.1747**	0.1770**
	0.0766	0.0771	0.0772	0.076	0.0766
_cons	-2.2624***	-2.2716***	-2.3041***	-2.3010***	-2.3161***
	0.2863	0.2885	0.2915	0.2881	0.2936
N	10240	10240	10240	10240	10240
Censored	2382	2382	2382	2382	2382
Uncensored	7858	7858	7858	7858	7858
Log pseudolikelihood	-5375.628	-5240.63	-5292.866	-4332.297	-4000.843
Wald chi2 [36]	1000.81***	797.01***	831.95***	116.6***	828.98***
Wald test rho=0 [1]	36.43***	22.92***	15.15***	43.07***	20.84***

Coeff/Robust standard errors (clustered by ID). ***. **. * denote 1%. 5% and 10% levels of significance. respectively. Sector dummies included